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Construction Engineering Research Laboratory

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Smart Bases

Autonomous Vehicle Pilot at Joint Base Myer-Henderson Hall

Project Report Summary and Recommendations

James P. Allen, Natalie R. Myers, Thomas A. Carlson, James T. Stinson, Richard J. Liesen, Lance L. Larkin, Ben Eubanks, and Juan L. Davila-Perez

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Under Project 479634, "FY19 Program Increase: Smart Bases"

Abstract

Military installations serve as strategic staging areas that are integral to national security. The Army is currently reconsidering how it views its installations as part of the battle space under multi-domain operations, which includes technology modernization efforts, such as the rapidly expanding field of connected and autonomous vehicle (CAV) technology. The DoD community and military installations have an interest in investigating autonomous transportation systems to determine their potential role in a broad range of military applications. CAVs capture, store, and analyze tremendous amounts of data. Military installations need to understand the data systems and processes involved in CAV deployments. To that end, the Army is conducting pilot projects that deploy updated and commercially-available CAVs on installations and within adjacent communities to further demonstrate their use and conduct research and development to optimize and inform the integration of this emerging technology. This report documents the deployment of Autonomous Vehicle (AV) technologies at Joint Base Myer-Henderson Hall for a 90-day pilot study to evaluate a commercially-available AV.

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Preface

This study was conducted as part of a Congressional Program Increase included in the 2019 National Defense Authorization Act under Project 479634, “FY19 Program Increase: Smart Bases” and is sponsored by the Assistant Secretary of the Army for Installations, Energy, and Environment (ASA[IE&E]) Strategic Integration. The ASA(IE&E) technical monitor was Mr. John Thompson.

The work was performed by the Engineering Processes Branch (CFN) of the Facilities Division (CEERD-CF), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Mr. Charles Schroeder was Chief, CEERD-CFN; Mr. Donald K. Hicks was Chief, CEERD-CF; and Mr. Alan Anderson was the Technical Director for Lands and Ranges, CEERD-CZT. The Acting Deputy Director of ERDC-CERL was Ms. Michelle Hanson and the Acting Director was Dr. Kirankumar V. Topudurti.

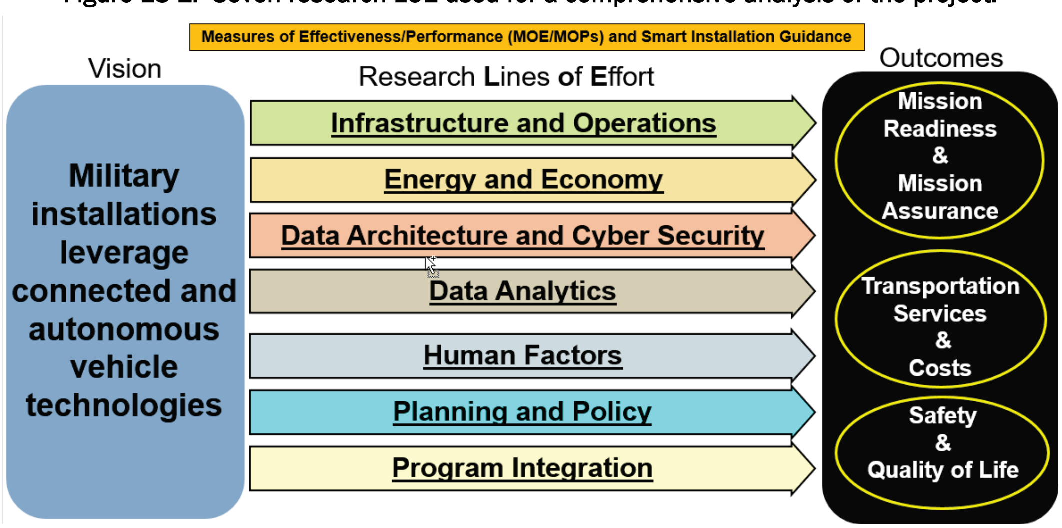
COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Executive Summary

Military installations serve as strategic staging areas that are integral to national security and require contemporary research and development (R&D) efforts to explore and exploit rapidly changing innovations such as autonomous vehicle (AV) technology. This report documents the deployment of AV technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90-day pilot study from 19 June to 27 September 2019 to evaluate the commercially-available Olli manufactured by Local Motors, Inc. and the AV technology that is provided by Robotic Research, LLC.

The central research question for the project was “How and why does an AV transportation option on JBM-HH impact mission readiness and assurance, transportation services and costs, and safety and quality of life?” The project was exploratory research using a mixed methods, single-case-study embedded design with multiple units of analysis that varied across the research lines of effort (LOEs). Evidence included field and participant observation, data collection and documentation, archival records, interviews, and surveys. The research LOEs reflected the desire to answer many emerging questions related to the dynamic nature of AV technology during a field study in a comprehensive approach that included the seven LOEs outlined below (Figure ES-1) to inform future smart installation guidance and policies and AV related measures of effectiveness and performance.

Figure ES-1. Seven research LOE used for a comprehensive analysis of the project.



The planning and policy LOE determined that the state of AV technology systems, government regulation, and product integration into the market is not yet mature enough to recommend formal policy and procedures for military installations to adopt AV systems into their formal fleets. However, this study serves as a foundational baseline for future AV studies and the findings highlighted the need for more installation pilots to examine other AV systems deployed in varied use-cases, climates, topographies, and community settings. The project had no AV related injuries or crashes; however, the low maximum speed of 12 mph disrupted normal traffic flow and identified a trade-off between risk and value, or risk and efficiency that requires more AV experience and technology development to determine policy. The use of AV technology must be incorporated with already proven transportation planning methodologies to ensure a holistic and deliberate approach that integrates transportation demands, origin/destination studies, infrastructure support, workforce requirements, user acceptance, accessibility, and local/state governance compliance on public roads.

The infrastructure and operations LOE demonstrated AV shuttle service of two AVs along the main routes of JBM-HH in a circular pattern from Wright Gate to South Gate during a 2-hour lunch period on weekdays over 7 weeks and for special events throughout the 90-day pilot. Electric vehicle charging infrastructure is critical in meeting operational goals of the AV fleet. The AV operated using a geo-fenced mapped route, which required 3 weeks for the technology to establish before transportation service availability, much longer than the anticipated few days planned for mapping. The AV operated successfully for 8,900 minutes of scheduled service, but inclement weather was a constraint. Existing roadway infrastructure on JBM-HH was capable of accommodating the AV, but the low 4-in. clearance was problematic at security checkpoints and made maneuvering the vehicle on a 7% grade was challenging. Optimizing AV operations would require additions and modifications to loading/unloading areas, traffic signals, and other communication infrastructure. The AV team required parking, charging, maintenance, and office space on the installation during operations. Future infrastructure investment on installations should consider technology that communicates and integrates with AV systems as part of their planning process.

The data architecture and cybersecurity LOE collected and analyzed data from AV sensors including light detection and ranging (LiDAR), radar, cameras, and vehicle telemetry data of 92,092 files at 6 terabytes, which were transferred to a secure Federal government cloud storage and are available for future data mining and analysis. The AV data and processing system on the vehicle had no reliance on external network access, which resulted in high security but a lack of real-time data transfer. Data transfer into secure government cloud storage occurred manually through periodic offloading via portable hard drives and overnight uploading with secure offsite internet connections. Edge computing and real-time data were limited highlighting the trade-off between risk and value. A standardized mechanism for indexing data from various sources of AV technology systems is needed to establish a solid data architecture and allow common data queries and effective application of post-processing methods and data analysis. Developing and documenting physical, operational, communications, and cybersecurity assessment protocols will require further research studies and use-case applications with multiple AV technologies at varied installation locations with diverse missions. Both the data environment and the applications require an integrated security approach that is currently ill-defined in the 4G and 5G networks.

The data analytics LOE examined potential exploitation of AV data for second-order impacts that may benefit the installation. AV sensors and technology are deployed to prioritize and optimize data gathering and decision-making for vehicle maneuver and navigation, and most of the artificial intelligence (AI) and data integration software for this purpose are proprietary products. Therefore, optimizing additional data analytics may require enhanced or additional sensors in the system. Reliability of the AV was uncertain based on instances of hard reboot requirements for the onboard system, which resulted in AV inoperability and data incongruity. Apparent fragility of the technology stack and integration with the AV sensor package demonstrated a need for continued development of more robust and resilient data processing and technology systems. A framework to count passengers onboard the AV with acceptable reliability using AI Cognitive Services was developed, but an effort to determine queue length of vehicles behind the AV through AI failed due to the low position of the external camera on the rear of the vehicle. Data mining review by time/location for incidents involving safety steward takeover of AV are possible but proved extremely time consuming. Integration of geographic positioning systems (GPSs) or other location data is essential for real-time data analytics. Edge computing use-cases that are most beneficial to installations for real-time analytics should drive future investment in AI and supplementary sensor integration into current AV technology.

The energy and economy LOE analyzed vehicle control unit and telemetry data to conduct an energy consumption study with a comparative analysis of the battery management system data to the vehicle operational limits. Battery drainage of the AV was higher than expected during operations and is a constraint. While the average range for the AV specifications was 20 miles for maximum load and 35 miles nominal, the realized range was on the order of 16 to 19 miles, or approximately 55% of nominal. Cost of operational energy for the AV ranged from \$0.05 to \$0.08/mile driven; and \$0.26 to \$0.30/hr of operation during fixed route transportation service based on the current price at JBM-HH of \$0.07/kWh. Efficiency of AV operation ranged from 0.69 kWh/mile to 1.14 kWh/mile. A 10% loss in energy between the charging station power required and the battery charge received was observed in the data, which is a reasonable planning factor for converting operational energy demand to supplied energy. Energy usage and consumption for AVs varies greatly with context of operations. The datasets were disparate and difficult to integrate for evaluation of energy use, miles driven, hours of operation, vehicle status, and location in a time sequence that allows detailed econometric analysis. Future data indexing and collection should consider this in the data architecture design stage for determining data collection frequency, latency, and integration goals of the project.

The human factors LOE examined the results of over 379 service members, families, and guests who rode the AV, with additional feedback from other users of the JBM-HH transportation system interacting with the AV as non-passengers. 154 surveys were gathered for analysis of trust in autonomy, basic demographics, and perception of safety. Results show AVs provide a perceived value to the installation and are considered intelligent, but comfort and trust have mixed responses. Riding the AV tended to increase trust in the vehicle. Ridership was much lower than expected but may be attributed to limited duration and extent of deployment, lack of advance marketing or advertising, and challenge in changing human habits and behavior. Riders and non-riders want more transportation options on JBM-HH, but achieving the “first and last mile” demands of users is a challenge and a better outreach mechanism is needed to inform people about the AV and its capabilities with links to transit hubs. Field observation determined low ridership for three primary reasons: (1) People wanted to know when and where Olli was operating and did not have that information, (2) People did not think it was safe and did not realize the person onboard was a safety steward that could intervene if needed,

(3) People did not realize it was available for rides after the mapping period and did not know it was free of charge. The social nature of transportation adds complexity to AV and human interaction. The project survey data did not detect before and after perceptions of the safety of the AV, highlighting an opportunity for future research related to safety and how trust is gained or lost through the use of technology.

The program integration LOE is an ongoing effort that explores how the application of AVs on installations impacts mission readiness and mission assurance in their function as strategic staging areas under multi-domain operations and in the joint/interagency environment. Mission assurance impacts were examined through the 17 mission assurance areas that DoD has used to operationalize resilience. AVs demonstrated potential to impact each of these areas if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DoD and varied mission sets. AV technologies present opportunities to improve mission readiness/mission assurance and inform decision-makers at installations, as well as leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work. The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the Northern Virginia Regional Commission (NVRC) pending funds availability. A “way forward” matrix is proposed that identifies strategic future smart bases and AV pilot locations, geography/climates, academic partners, and joint force mission sets for a structured R&D framework that builds on this foundational project.

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1 Introduction

1.1 Background

Military installations serve as strategic staging areas that are integral to national security. The Army is currently reconsidering how it views its installations as part of the battle space under multi-domain operations (MDO). This review includes technology modernization efforts, such as the rapidly expanding field of connected and autonomous vehicle (CAV) technology. The DoD community and military installations have an interest in investigating autonomous transportation systems to determine their potential role in a broad range of areas including infrastructure, security, economic impacts, cyber-activity, and communications. CAVs capture, store, and analyze tremendous amounts of data. Additional methods of processing this raw data could facilitate transportation optimization. Moreover, such data must be protected from external exploitation. Appendix A to this report provides a primer on this subject and includes a comprehensive list of commercially-available CAVs as of this writing.

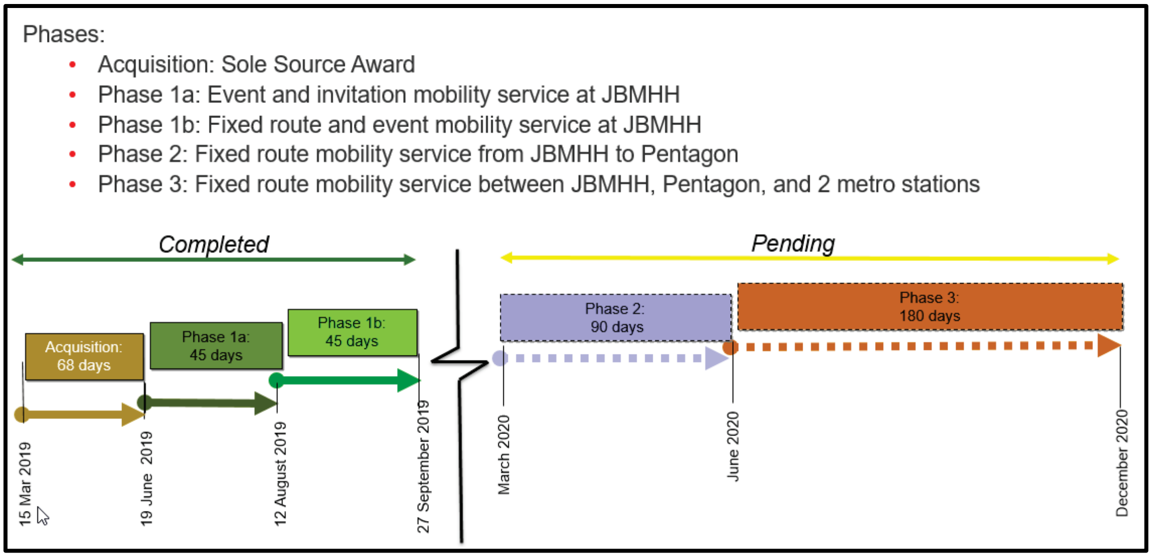
Military installations need to understand the data systems and processes involved in CAV deployments. To that end, CAV demonstrations have been conducted on Army installations through the U.S. Army Research Laboratory (ARL) and the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC), Ground Vehicle Robotics program entitled Applied Robotics for Installations and Base Operations (ARIBO). The ARIBO program demonstrated CAV use on installations and matured the technology through increasing stages of chauffeured, safety operator, and fully autonomous vehicle (AV) operations within limited internal installation routes. The ARIBO projects occurred from 2016 to 2018 at locations including Fort Bragg, NC and West Point USMA, NY. Although the ARIBO program is no longer active, development of CAV technology has continued. The reorganization that resulted in the establishment of Army Futures Command effectively focused the Army's institutional expertise in CAV technology at ARL and the newly formed U.S. Army Combat Capabilities Development Command (CCDC) Ground Vehicle Systems Center. These commands are continuing to investigate CAV technologies and their potential application in combat missions. The U.S. Army Engineer Research and Development Center (ERDC) has taken a leadership role on this project based on its expertise in infrastructure, energy, data analytics, and planning for installations to investigate and inform CAV deployments on installations. ERDC's efforts will improve mission readiness and inform decision-makers at installations as they seek to establish a common operating picture to automatically identify integrated optimization choices using: Big Data, Predictive Analytics, and AI.

In February 2019 a collaborative submission for a CAV demonstration project was proposed to Local Motors, Inc. by Joint Base Myers-Henderson Hall (JBM-HH), Marine Corps Installations Command (MCICOM), and ERDC with the support of the Office of the Assistant Secretary of the Army (IE&E), DASA Strategic Integration as part of the "Greater Washington Fleet Challenge." On 15 March 2019, an official notice by Local Motors, Inc. of the selection of JBM-HH as the regional location for the demonstration was received. A sole-source contract to acquire data from the AV sensors and weekly operational reporting from Local Motors during the AV demonstration was approved. This 90-day demonstration formed the Phase 1 military installation AV deployment that is the time frame for this report.

A broader regional effort by the Northern Virginia Regional Commission (NVRC) and its stakeholders to provide "first and last mile" transportation options to local commuters and to reduce the traffic burden in the regional highway system includes Phase 1 as well as follow-on Phase 2 and 3 projects that provide AV services from JBM-HH to key transit hubs and employment institutions such as Metro stations and the Pentagon. Figure 1 shows the envisioned timeline and phases of this broader regional effort. The military liaison with the NVRC is a key integrator between the many installations and the regional transportation plans.

The Army now needs to conduct pilot projects that deploy updated and commercially-available CAVs on installations and within adjacent communities to further demonstrate their use and conduct research and development (R&D) to optimize and inform the integration of this emerging technology. This report documents the deployment of AV technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90-day pilot study from 19 June to 27 September 2019 to evaluate the commercially-available Olli AV manufactured by Local Motors, Inc. and Robotic Research, LLC.

Figure 1. Timeline and envisioned phases for the deployment of AV technology in the Northern Virginia Region. Phase 1 is complete and occurred completely on JBM-HH. The military liaison with the NVRC is a key integrator between the many installations and the regional transportation plans.



1.2 Objectives

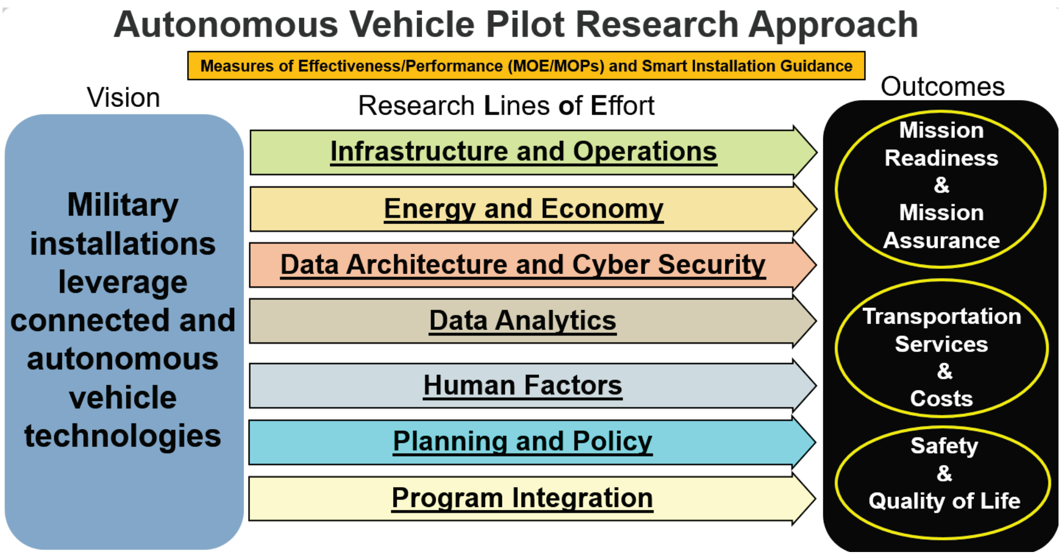
The objective of this project was to document the deployment of AV technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90 day pilot study from 19 June 19 to 27 September 2019 to evaluate the commercially-available Olli AV manufactured by Local Motors, Inc. and Robotic Research, LLC. Specific objectives were to

- Explore the data captured and the process required to employ AVs during the Olli AV deployment at JBM-HH
- Transfer data collected by the AVs and document process steps and findings during the planning, site survey, setup, operational test, demonstration, and employment of AV technologies at JBM-HH, and within the surrounding community for evaluation of commercially-available AVs like the Olli.

1.3 Approach

The central research question for the project was "How and why does an AV transportation option on JBM-HH impact mission readiness and assurance, transportation services and costs, and safety and quality of life?" The project involved exploratory research using a mixed-methods, single-case-study embedded design with multiple units of analysis that varied across the research lines of effort (LOEs). Evidence included field and participant observation, data collection and documentation, archival records, interviews, and surveys. The research LOEs reflected the desire to answer many emerging questions related to the dynamic nature of AV technology during a field study in a comprehensive approach that included seven LOEs (outlined in Figure 2) to inform future smart installation guidance and policies and AV-related measures of effectiveness and performance.

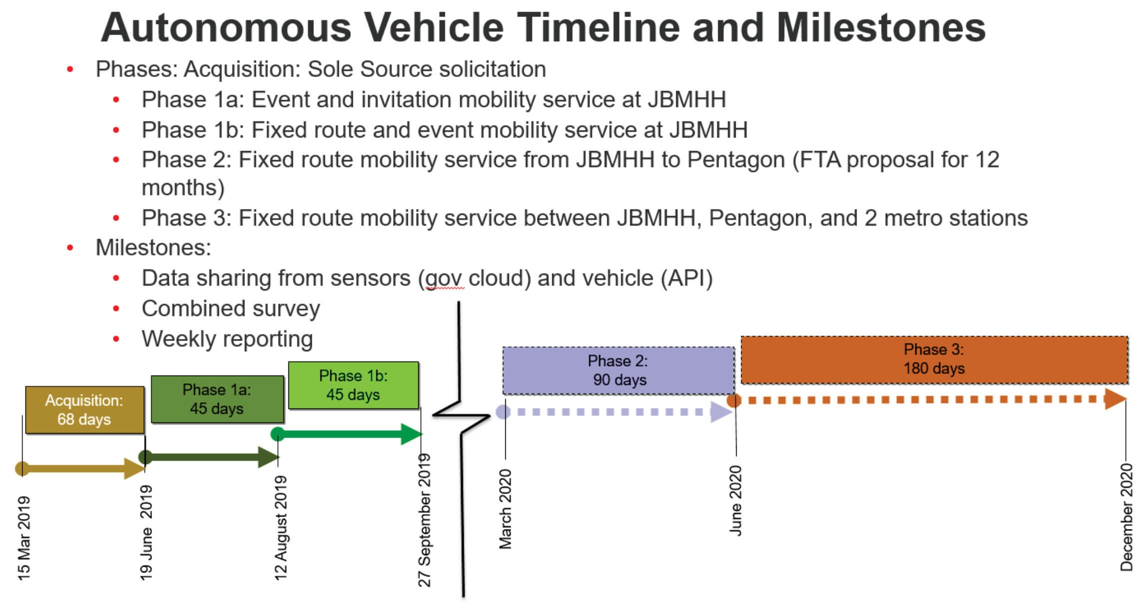
Figure 2. Seven research LOE used for a comprehensive analysis of the project.



1.4 Scope

The project included a 90-day time period of Olli operations. The project used Olli #10 and Olli #13, which represent the sequence of (version 1.0) Ollis built by Local Motors. The pilot was conducted entirely within JBM-HH perimeter on installation roadways. Note that, due to limited resources from local and state stakeholders, the Phase 2 and 3 aspects of this project, which would extend off JBM-HH, are still pending and thus not included in this report. Figure 3 shows the timeline and phases along with key milestones achieved and dates.

Figure 3. Timeline and milestones achieved.



1.5 Significant milestone dates

The anticipated timeline and key activities originally planned at JBM-HH included

- 3 April 2019: Begin deployment planning and site survey.
- 4 April 2019: JBM-HH announced to be National Capital Region Local Motors Olli Fleet Challenge location for AV pilot.
- April to mid-May 2019: Infrastructure setup and operational testing, vehicle and route setup and operational testing.
- Mid-June 2019: Mobility service begin operation.
    - Phase 1 service: internal JBM-HH route for 90 days.
    - Phase 2 service: addition of route from JBM-HH to Pentagon from day 91 to day 180 if milestones achieved.
    - Phase 3 service: addition of route to two Metro stations at Rosslyn and Pentagon City from day 181 to day 365.
- 16 June 2019: Federal acquisition process completed with award of sole-source, firm fixed price contract to Local Motors for data transfer and process reporting during Phase 1. Two additional options included in contract continue data transfer and process reporting during Phases 2 and 3.
- 19 June 2019: JBM-HH Launch Event and Olli begins Phase 1a operations for invitational events. Launch event speakers include Cathy McGhee, Director of Research and Innovation at the Office of the Virginia Secretary of Transportation; Jay Rogers, CEO and co-founder of Local Motors; along with Army and Marine Corps leadership.

- 12 August 2019: Phase 1a completed with total of 16 events and 171 riders on Olli for 0.9-mile demonstration route. Phase 1b operations begin along 4.4-mile fixed route from Wright Gate to South Gate of JBM-HH with 14 stops and two Olli AVs between 1100-1300 daily.
- 18 September 2019: Conducted afternoon roundtable at JBM-HH of all stakeholders to document project outcomes related to mission assurance and mission readiness, safety and quality of life, and transportation services and costs.
- 27 September 2019: Phase 1b completed with total of 7 weeks (35 days) of fixed route transportation service with over 450 miles traveled, 208 riders, 12 events, and 137 safety steward takeovers conducted.
- Deployment closure after 1-year operation.

1.6 Roles and responsibilities

The Federal roles and responsibilities for the JBM-HH deployment of CAVs were formalized in a Federal Memorandum of Agreement (MOA). A summary of the roles is

- ERDC-CERL as R&D project and contracting lead
- JBM-HH as project operation and support lead
- ASA IE&E as strategic communication lead
- MCICOM as joint integration lead and strategic communication secondary lead.

Appendix 0 presents a business case analysis regarding the JBM-HH CAV technology pilot. This report, which was prepared for ASA(IE&E), supports the Army goal to increase readiness, build resilience, increase efficiency, lower costs, and improve the quality of life of service members and their families. To accomplish that goal, within the ASA(IE&E) role as strategic communicator, the business case analysis captures a cost-benefit of expected returns to the Army.

2 Planning and Policy

2.1 Research focus and methods

This LOE captures the individual key contributions to successful operations of AVs on base from a holistic perspective of planning and policy. Planning ensures that AV operations are safe, that they meet the needs of the users, and that they are not a burden to the mission. Policymakers may consider regulating procurement processes, vehicle activities, and vehicle capabilities, as well as other issues including privacy, security, traffic law, and environmental regulations. This chapter presents the JBM-HH AV deployment activities and their implications for planning and policy.

The project team's weekly synchronization meeting, held Wednesday afternoons for 1 hour via teleconference, was the mechanism for tracking how the AV pilot was implemented throughout the planning, operation, and closeout phases. All stakeholders were welcomed to participate. Careful notes and observations from each meeting provided a list of players, the activities and concerns of each player, and the workflow of activities, including lead and cycle times. Recommendations reflected the collective thoughts of the stakeholder group gathered from the project's after-action review, during which all stakeholders met in person at JBM-HH to discuss individual viewpoints and lessons learned.

The following section provides a broad overview of AV policy at the local, state, and national levels — to give a "big picture" view of the JBM-HH pilot, from a national perspective.

2.2 Current policy and regulations

To date, the process of formulating AV policy has been limited. This is likely due to the lack of clear precedent that might guide policymakers' actions, and to the desire to avoid burdening the automotive and software industries with excessive regulations. There is a clear intent to facilitate AV testing and full deployment through all levels of government and an expressed desire to include as many actors in the process as possible. The general role of each level of government follows:

- Federal legislation and administrative regulations pertain to such matters as highways, vehicle safety, and fuel efficiency standards. The

National Highway Traffic Safety Administration (NHSTA) and Federal Motor Carrier Safety Administration (FMCSA) has led the bulk of the Federal response to AVs. This agency's embraces a permissive approach marked by regulatory restraint and implicit trust in AV developers (see section 2.3). FMCSA has a long history of oversight and regulation of commercial carrier applications of all vehicles; its authority will also apply to specific AV use-cases that fall within their purview.
- State legislation and administrative regulations pertains to such matters as licensing of vehicles and operators, minimum vehicle standards, insurance, roadway usage, and traffic laws, and other issues including privacy, security, criminal law, and environmental regulations.
- State common law pertains to property, tort, and contract matters.
- Local ordinances address traffic, pedestrian, and bicycle safety and parking.

Key policy challenges not clearly tied to a jurisdiction are data protection rules and insurance markets.

2.2.1 Federal policy

The USDOT first released *Preliminary Statement of Policy Concerning Automated Vehicles* (NHTSA 2013) (AV 1.0) in 2013. AV 1.0 covered the National Highway Traffic Safety Administration's (NHTSA) research plan, definitions of automation levels, and recommendations for states focused on AVs. Updated in September of 2017, *Automated Driving Systems 2.0: A Vision for Safety* (NHTSA 2017) (AV 2.0) provided voluntary guidance to industry and technical assistance and best practices to states that offered a path forward to the safe testing and integration of automated driving systems. *Preparing for the Future of Transportation: Automated Vehicles 3.0* (AV 3.0) (USDOT 2018), which was released in October 2018, remains the comprehensive policy guide at the national level. AV 3.0 is divided into two sections:

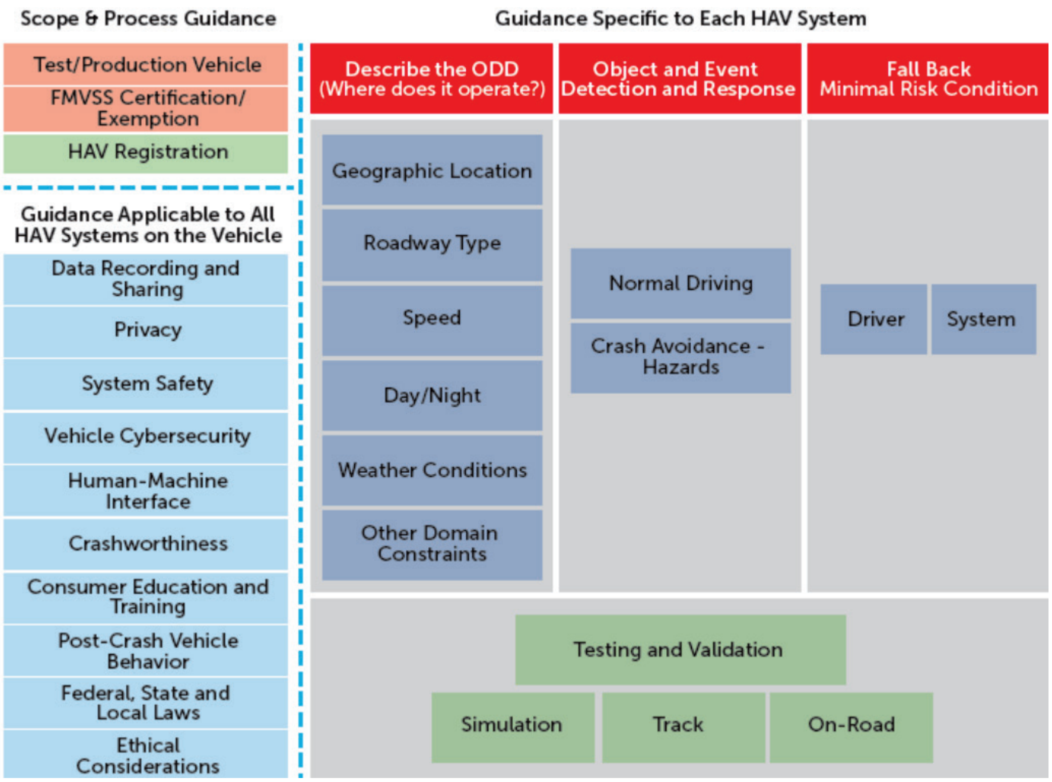
1. "Automation and Safety" provides 12 safety elements to support the safe testing and implementation of highly automated (Level 3-5) technology. This section is designed to help AV manufacturers identify and resolve safety considerations before deployment. For each element, the report provides safety goals and best practices for attaining those goals.
2. "Roles in Automation" starts by outlining the Federal and state roles in regulating AVs. NHTSA is responsible for regulating motor vehicles and motor vehicle equipment, and states are responsible for regulating the

> human driver and most other aspects of motor vehicle operations. From that foundation, it then provides state legislators and highway safety officials with a framework of best practices for developing their own laws and regulations. The goal of this guidance is to develop a consistent, unified national framework of laws and policies that promotes the development and implementation of AVs (USDOT 2018, p. 5).

Most recently (January 2020), the USDOT in partnership with the White House National Science and Technology Council released *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0* (AV 4.0) (USDOT 2020), which provides high-level guidance to stakeholders. The document details 10 U.S. Government principles for protecting users and communities, promoting efficient markets, and facilitating a standardized R&D approach in AVs. Many of the Federal government's efforts have been focused on funding research and policy development on AVs, including the successful initiation of pilot programs. There have been congressional legislation proposals regarding AVs, but nothing has passed.

FMCSA and NHTSA are involved in making and enforcing the Federal Motor Vehicle Safety Standards (FMVSS), which specify design, performance, and safety requirements for vehicles that operate on public roads in the United States. This entails complex implications for AV technology systems and their integration into the public transportation system. While some AV companies are simply applying robotics to existing and already FMVSS-approved vehicles, other AV innovations involve building custom vehicles for which application of existing regulations and standards is somewhat ambiguous, waivers for operation are required, or operation off public roads is constraining. Figure 4, which shows the framework for U.S. Department of Transportation's (DOT's) Vehicle Performance Guidance, identifies the key areas to be addressed by manufacturers and other entities before testing or deploying AVs on public roadways.

Figure 4. Key areas to be addressed by manufacturers and other entities before testing or deploying the vehicle on public roadways.



Source: "US policy on autonomous cars drives into unchartered territories," Anusuya Datta, Geospatial World, Oct 2016

2.2.2 State policy

At the state level, a wide variety of laws and regulations have been introduced and enacted. Since 2012, at least 41 states and the District of Columbia have considered legislation related to AVs. Twenty-nine states and the District of Columbia have enacted legislation related to AVs. Governors in a handful of states have issued executive orders related to AVs. (https://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx)

Among the states that have enacted legislation related to AVs, there is some variation in the statutory language and the focus of legislation regarding these topics:

- The "drivers" (people sitting behind the steering wheel) need to be pre-approved and they need to have proof of training by the manufacturer.
- These "drivers" must also have the ability to take control of the car (via steering wheel, gas pedal, and brake pedal, at a minimum) at any time.

- Manufacturers are required to maintain some level of insurance coverage.
- Manufacturers need to show that their driverless vehicles have been tested and can safely comply with all applicable traffic laws.
- Driverless vehicles must store sensor data for a pre-established amount of time.
- Some reporting (of incidents, at a minimum) is required.

Currently, there is little consistency or precedent on a safety and licensing framework among the existing and emerging legislation. Some states have opted against the creation of new regulations for AV testing or operation based on the concern that previous laws have restricted research in those states that passed testing regulations. AV producers must also arrange with state agencies for vehicle registration and safety inspection.

2.2.3 Local policy and key topics

Local government involvement in the advancement of AVs is minimal. A few cities are making news as AVs are being tested on their streets (notably Mountain View, California, Las Vegas, Nevada, and Austin, Texas); however, the cities are not necessarily investing in the technology or actively forming partnerships with the technology developers.

Cities are only just beginning to anticipate the implications of the rollout of AVs and to establish approaches to the impending phenomenon in the form of "comprehensive plans." Comprehensive plans set strategic direction that should address anticipated shifts that will result from the introduction of AVs. The following sections summarize some of the elements that cities are incorporating into their comprehensive plans.

2.2.3.1 Traffic management

Traffic signals, signs, street marking, loading/unloading lanes, and parking will likely need to change to accommodate AVs, especially where they can help reduce potential conflicts between vehicular traffic and non-motorized road users, such as cyclists and pedestrians. These will also be important during the transitional phase where AVs and non-AVs share the roadway. Optimizing a roadway for AVs will also require the installation of various types of sensors and communications technology to allow vehicles to travel more efficiently. Local decision-makers are still struggling to determine who will pay for the installation of AV-friendly traffic management systems.

2.2.3.2 Related infrastructure

Large numbers of AVs on city streets will generate additional types of infrastructure needs. Communication networks based on available Wi-Fi will be crucial not just to vehicles, but also to the occupants who will be free to teleconference, access the internet, and enjoy other activities instead of needing to watch the road. Questions remain regarding who will install infrastructure and provide services on these Wi-Fi networks. Similarly, assuming that future AVs will largely be electric vehicles, where and when will they charge, and how will this impact the power grid?

2.2.3.3 Liability

Smart transportation systems will rely on a complex interaction between mechanical vehicles, the software within those vehicles, the software and available technology within the roadways, and people. City managers are concerned with who will be liable when an accident occurs, and how this will affect insurance requirements. The liability regime that currently supports auto insurance is based on individual driver liability; this may soon change to reflect a greater emphasis on the liability of the manufacturer of an AV. Anderson et al. (2018) identify liability issues ranging from the inability of the insurance industry to measure aspects of AV technology (as they currently do with drivers), the need for national standards, and the potential need to insure against AV hacking by malicious actors. For example, if a foreign power hacked all AVs in the United States and directed them all turn left at the same time, the resulting calamity might require catastrophic event insurance, such as flood insurance (https://www.rand.org/pubs/conf_proceedings/CF383.html).

2.2.3.4 Workforce

The introduction of AVs may affect countless industries such as construction, manufacturing, communication, energy, and most directly, transportation. The transportation industry of truck drivers, delivery people, taxi drivers, rail workers, and transit workers will likely see their current jobs change significantly as AVs remove the need for a person to physically move goods and people from place to place. Note, this does not equate to a loss of jobs, but rather a shift in responsibilities. Truck drivers, for example, perform all kinds of tasks, from checking vehicles and securing cargo, to maintaining logs and providing customer service, all functions that AVs are never intended to perform. Furthermore, Mudge and Kornhauser

(2019) argue that Transportation Network Companies (TNCs), of which Uber and Lyft are prime examples, are generating a new transportation demand segment. Despite being known as “ride-sharing” firms, they serve either single riders or single groups of riders that, for reasons other than transport efficiency, were traveling together. The assertion is that these travelers increase overall vehicle miles traveled, divert travelers from transit, and contribute to a loss of unionized taxi drivers. In the most general sense, AVs will undoubtingly create workforce changes.

2.2.3.5 Equity

AVs will have notable ramifications for social equity, particularly as it relates to equitable access to resources, jobs, and amenities. While it is too soon to determine who will benefit most from AVs and whether AVs will improve or hinder access to affordable mobility, planners are considering the equity implications to ensure that the safety and mobility benefits of AVs are not only for those who can afford them. In cities and on military installations, for example, access to health care and veterans’ services offer compelling use-cases related to the equitable access to AV resources.

2.2.4 Current state of pilots

Given the physical and regulatory complexities of public roads, many AV developers are testing in self-governed districts/closed campus, such as colleges and military bases, where strict rules on road use do not apply. At the time of publication, MCity (operated by the University of Michigan) and GoMentum (operated by AAA Northern California, Nevada, and Utah) were the most prevalent test sites. Thus far, single-occupancy vehicles (traditional cars) are the prevailing mechanism for autonomous technology experimentation although a number of cities and universities are testing shuttles as a potential expansion of, or replacement for, existing public transportation options. Several cities also have an AV pilot presence in the form of small sidewalk delivery robots, and states, along with the Federal government, are testing autonomous freight and/or highway technologies. All pilots contribute to our understanding of this technology and its impact within surrounding communities.

The mechanisms for initiating, funding, and managing pilots demonstrate a wide range of possibilities, from formal agreements to impromptu demonstrations, funded with a mix of local, Federal, and private money. This phenomenon reflects a permissive Federal regulatory environment that allows pilot entities the flexibility to develop relationships at will. This gap in legislation offers an opportunity to craft a localized approach to AV piloting that addresses specific demonstration goals. Working with strategic partners like USDOT, states, and regional entities near installations; and with the American Association of State Highway and Transportation Officials (AASHTO) on other pilots, will inform this ongoing process so military installations can integrate the latest information, regulations, and priorities.

2.3 Planning and policy data and findings

2.3.1 Stakeholders, collaboration, and roles

Stakeholders for the JBM-HH deployment were invited to participate in a weekly synchronization meeting held Wednesday afternoons via teleconference (15 May 2019 to 16 October 2019). The formal pilot partners were initially invited, and others joined either by direct invitation or voluntarily after hearing about the pilot by word-of-mouth. All were welcomed. The meeting format was a collaborative discussion and information sharing session to track action items and resolution. ERDC hosted and led the web-based meeting. Table 1 outlines the standing agenda for the meeting and lists the key pilot partners.

Table 1. General synchronization meeting agenda.

Welcome and Roll Call	
Introduction—Review of where pilot sits with respect to overall timeline and milestones	
Stakeholder Updates / Status Reports	
	U.S. Army Engineer Research and Development Center
	Local Motors
	Robotic Research
	Joint Base Myer-Henderson Hall
	Maine Corps Installations Command
	Northern Virginia Regional Commission
	Virginia Department of Transportation
	Arlington County
	Public Affairs
	Others
Outstanding Issues	
New Issues and Action Items	
Closing—Summary of anticipated products	

At least one member from each stakeholder group listed in the agenda attended each synchronization meeting. On average, there was 1-3 other stakeholder groups participating. These included staff from other installations interested in pursuing AV pilots and academic institutions interested in the pilot data. Subject matter experts occasionally joined for specific conversations (e.g., discussions regarding testing traffic light behavior), but were more often consulted outside of the synchronization meeting with results reported to the stakeholder group. Appendix B provides a comprehensive list of the pilot's stakeholders (defined as any entity that interacted with the pilot in some capacity, big or small).

Largely, there was active and consistent participation. Some participants inevitably generated requests that they believed to be simple, but in practice may be challenging; conversely, others hesitated to ask for fear of generating overburdening requests. Regular discussions mitigated these scenarios by ensuring clear relationships and roles within the stakeholder group.

The Federal roles and responsibilities for the JBM-HH AV deployment were formalized in a Federal MOA:

- JBM-HH as project operation and support lead
- ERDC-CERL as R&D project and contracting lead
- ASA IE&E as strategic communication lead
- MCICOM as joint integration lead and strategic communication secondary lead.

The following section provides more detailed descriptions of the activities and authorities of the key players.

2.3.1.1 Joint Base Myer-Henderson Hall Major activities and authorities

JBM-HH conceived its role to provide the demonstration site over a number of years of activities and coordination. JBM-HH has a strong history of innovation in military technologies and transportation that dates back to Wilbur Wright and the first manned military test flights in 1909. In 2015, JBM-HH hosted an Industry Day that invited AV technology companies and related entities to provide ideas and opportunities related to their unique systems that may integrate with military needs. MCICOM, Local Motors, Robotic Research, and many other entities participated in the Industry Day discussions. JBM-HH has a long history of working with the NVRC to address regional traffic congestion, reduce the number of single-occupancy individual commuters, and solve the "first and last mile challenge" of the transportation system. Thus, a natural collaboration between JBM-HH, MCICOM, and NVRC was established. Its long history of installation-related R&D with the joint services, and participation in the Transportation Research Board Military Transportation Committee, established ERDC as the project's research lead in evaluating AV technologies on installations.

JBM-HH did not manage AV operations or conduct research activities. They assumed no liability. Two staff members from the Plans, Analysis, and Integration Office (PAIO) and Network Enterprise Center (NEC) were tasked with managing the pilot on top of their current workload. Appendix C lists the key activities of the PAIO and NEC personnel.

NEC staff conducted and coordinated daily requirements and oversights of the AV mobility service, ensuring that it met all JBM-HH processes, procedures, and protocols. NEC staff were the conduit for all garrison permissions.

JBM-HH Public Affairs Office (PAO) was the lead communication support. PAO staff supported all advertisement of the Olli pilot. Additionally, PAO staff disseminated AV user and education material within JBM-HH. This included information to base departments on what to expect during the pilot and how to support efforts. The PAO and DoD newspaper, *Pentagram*,[*] routinely published articles regarding the pilot and the route schedule. Appendix D provides first page images from all articles.

JBM-HH staff reported deriving a significant educational value from the pilot, including information on the specific nature of the technology, its abilities and particularities, and how the garrison's own typology impacts pilot performance. As a pilot garrison, JBM-HH got a "front-seat view" of how AV reacts to its physical space, from braking for tree leaves blowing in the wind to anticipating the challenges of changing elevations and routine Soldier activities. JBM-HH staff also reported that they had learned more about the public's willingness to accept AV presence and, in turn, about how to use the AVs to educate the public and better solve installation transportation demands.

[*] https://www.dcmilitary.com/*Pentagram*/eedition_archive/

2.3.1.2 Engineer Research and Development Center Major activities and authorities

ERDC functioned as the lead for R&D activity by acquiring relevant data and processes that were generated by AVs during the mobility service demonstration. ERDC formalized this role through an MOA with JBM-HH and MCICOM (see Appendix E). ERDC provided eight staff members, each with specific expertise to an LOE. LOE leads determined what data to collect, ensured its collection, and evaluated the results. Data collection required an ERDC staff member to be on site at JBM-HH each week of operation, and also required a contract with the service provider, Local Motors, to obtain specific operational data. Funding for ERDC researchers came from FY 2019 NDAA Congressional Program Increase, Smart Transportation: Autonomous Vehicle Pilot project.

The objective of the Smart Transportation program is to explore the use of connected AVs at military installations that are integrated with regional communities to lower costs, improve Soldier and family quality of life, and enhance mission readiness. Under this program, ERDC's overall goal was to inform Army and DoD policy regarding the capabilities/constraints of AV technology and the potential for enterprise-wide adoption. To this end, ERDC, in partnership with MCICOM and the Assistant Secretary of the Army (ASA IE&E), served as a liaison with the larger DoD community in promoting key findings and recommendations, and in transferring results to other AV pilots within the DoD. Specific pilots include AV demonstrations at Fort Carson, Colorado, Marine Corps Air Station (MCAS) Miramar, California, and Joint Base Andrews, Maryland. The JBM-HH pilot was highlighted in AV 4.0 (January 2020).

ERDC entered an educational partnership agreement with George Mason University to share pilot data to support academic research. A clause was added to the Fort Carson AV pilot for ERDC to share JBM-HH pilot results (December 2019). Agreements were attempted with Virginia Department of Transportation (VDOT) to support its regional efforts. However, both parties failed to come to agreement while trying to identify the appropriate mechanism as a result of the complexity involved with data-sharing agreements, and the fact that Phases 2 and 3 did not have adequate funds identified.

ERDC staff reported that there were difficulties in distributing the data collected from the Olli AVs to stakeholders. AVs capture high-definition video, which can reveal critical infrastructure and PII (Personally

Identifiable Information). Before sharing data, a classification level must be established for each component of the data. Since there was no readily available comparable guide to do this, a security classification guide process (which takes months to complete) was initiated. ERDC, in partnership with JBM-HH, classified the data as sensitive research and is pursuing a formal security classification guide for the AV on installations program.

2.3.1.3 Local Motors major activities and authorities

Local Motors provided two Olli AVs and four dedicated staff members to operate the vehicles—a fleet manager, two safety stewards, and a service technician. Additional support staff were readily available (e.g., marketing and vehicle operations staff). Local Motors managed all setup, operation, and removal of the AVs. Local Motors assumed all liability and managed the acquisition of all required national and local operating permits.

Local Motors delivered the Olli AVs to JBM-HH. On arrival, garage space and charging equipment was finalized. Local Motors staff installed the real-time kinematic (RTK) station on JBM-HH. Local Motors, in coordination with Robotics Research, performed route mapping. Local Motors staff operated the Olli AVs as directed by either JBM-HH or ERDC staff during the 90-day pilot. This included limited evening and weekend operations. No vehicle was run without a safety steward present. The service technician transferred all data off the vehicle to data storage weekly. The fleet manager captured and reported all data contracted by ERDC. This data included a site survey report for setup, infrastructure and route survey, weekly mobility service reports, and shutdown and removal report.

Critical to Local Motor staff was easy access on and off the installation as well as to the Olli garage. To support this need, the fleet manager was allowed to have a DoD common access card (CAC) and a key to garage and/or office space. The fleet manager office space was valuable in that if offered a dedicated and convenient location where base personnel could contact Olli operators and vice versa.

Local Motors staff reported logistical lessons from the pilot. For example, the use of one charging station for two Olli AVs was challenging, especially since they were parked head-to-tail. This required both Olli AVs to be moved (e.g., switch places) each time one needed to be charged. Not having a high-speed uploader on the installation for the Olli hard drive was also cumbersome. Stewards would drive to the National Harbor

Headquarters (45+ minute drive) several evenings to connect the external hard drive to the uploaders, and then again to pick it up in the mornings. Finally, many riders commented to the stewards that the route did not take them to their preferred destinations. Local Motors learned that they must do a thorough analysis to ensure that the route adequately supports their community needs.

2.3.1.4 Northern Virginia Regional Commission major activities and authorities

NVRC's military liaison was a champion of the pilot. NVRC's regional interest is to reduce the quantity of single-occupancy cars commuting to and from work each day, and to use AVs to improve quality of life by solving the first and last mile challenges. NVRC's military liaison supported the Greater Washington Fleet Challenge proposal submission with JBM-HH and MCICOM. On award, NVRC led the invitational rides, Phase 1A, and continued invitational rides through Phase 1B. Invitational rides served as public information sessions where community groups could experience AVs in operation. The NVRC military liaison participated in all the invitational ride events to answer questions and provide a regional perspective of the pilot.

The NVRC military liaison sought subject matter experts to advise the pilot effort, for example, by meeting with AASHTO, USDOT/NGHSJA and local jurisdictions. The liaison also arranged for the pilot to be showcased on the TV Show *Emerald Planet* on 25 August 2019 (Emerald Planet 2019). Guests included:

- Lt Col Mark A. Paolicelli, USMC & Deputy Base Commander, Joint Base Myer-Henderson Hall (JBM-HH)
- Peggy Tadej, Director, Military Affairs, NVRC
- David C. Woessner, Executive Vice President, Corporate Development and Regulatory Affairs, Local Motors
- Major Kyle Holway, Strategic Engagement and Mission Sustainment Branch, G-7 Modernization and Development Directorate, MCICOM
- Richard G. Kidd, IV, Deputy Assistant Secretary of the Army for Strategic Integration, Office of the Assistant Secretary of the Army, Installations, Energy, and Environment, U.S. Department of Defense.

NVRC's partnerships and knowledge of the region provided invaluable support in this regard. NVRC additionally applied for awards and additional grants to potentially continue and further the pilot effort for the planned Phases 2 and 3. Both NVRC and ERDC submitted several conference proposals to highlight results and convey the story.

NVRC staff reported that experiencing and interacting with AVs is valuable to increasing community acceptance and support. However, a 90-day pilot was not long enough to address all of NVRCs concerns including the first and last mile transit challenge, handicap accessibility, digital infrastructure connectivity, and public safety/involvement.

2.3.2 Milestones and Workflow

The AV pilot was done on an expedited timeline to leverage the availability of the Olli AVs and to use them to the maximum extent possible during the summer months when the weather was most probable to permit AV operations and the large number of visitors were likely to be on JBM-HH. Any AV deployment on an installation will have similar activities required.

Key milestones at JBM-HH included:

- 3 April 2019: Begin deployment planning and site survey
- April to mid-May 2019: Infrastructure setup and operational testing, vehicle and route setup and operational testing
- 19 June 2019: Mobility service begin operation Phase 1 service, internal JBM-HH route for 90 days
    - 19 –31 July 2019: Invitational mobility service along demonstration route for 45 days
    - 12 August –30 September 2019: Fixed route mobility service for 45 days
- 30 September 2019: Mobility service end operation Phase 1

Appendix F includes a detailed timeline of events and activities.

The Olli AV pilot milestones can be categorized into four phases: (1) acquisition, (2) planning (or setup), (3) operation, and (4) closeout. Acquisition and planning consume the greatest effort of time and labor. The following sections describe the workflow of each phase, centering on the key planning questions.

2.3.2.1 Acquisition

Identifying the necessary people, technology, property, and other materials is an important first step to delivering an AV service. These resources may be acquired from both internal and external sources.

Use-Case Selection: For what purpose(s) will the AV be used? This was a given for JBM-HH as they were selected to receive two shuttle/mobility vehicles from the Olli Fleet Challenge. But many sites will need to establish whether AVs will move people, goods, and/or support tasks such as lawn mowing or airfield cleanup along with what type of vehicles and how many. This may include a Request for Information (RFI). It is important to match the vehicle with the use-case. Consider the physical environment, infrastructure, and exiting behaviors including speed of existing vehicles. Following the pilot, JBM-HH noted that a single charging station was inadequate for their use-case design.

Stakeholders: Who is the core team willing to manage and see the project through to completion? Stakeholders include the vehicle provider and operator, automated system provider, deployment community, and research community. A MOA between the key stakeholders was useful in the JBM-HH pilot to define roles and ensure all roles were covered.

Funding: How will activities be funded? All activities will require some level of funding. It is important to determine what those levels are and who will pay the bill. Local Motors funded the Olli Fleet Challenge, providing JBM-HH with the opportunity to test two Olli AVs for their desired use-case. Local Motors has hosted several pilot studies since launching the initiative in late 2018 and the results have benefited both the users and the manufacturers in developing and demonstrating many potential uses for Olli. For this pilot study, Local Motors supplied two Olli 1.0 AVs and the operation and maintenance workforce. JBM-HH provided the test site (funding any necessary infrastructure requirements) and the use-case. Army and ERDC funded all research activities from Congressional Program Increase, Smart Transportation: Autonomous Vehicle Pilot. This included a sole-source contract to Local Motors for specific data collection, transmission, and process reporting.

Permits and Waivers: What permissions are needed to operate? Local Motors was responsible for securing all local and national permits. According to Virginia law, any vehicle that is being tested or operated on roadways that are closed to the public do not have to be titled, registered, or safety inspected before operations. JBM-HH was responsible for gaining permission to operate the AVs on base through the Army.

2.3.2.2 Setup

Setup requires breaking down the scope of the project into manageable sections with clear milestones and a strong communication plan.

Infrastructure: What infrastructure and/or supplies are needed to successfully operate? For Olli 1.0, this included a temporary RTK antenna to ensure GPS accuracy, a charging station with appropriate power fixtures, garage space, and office space. Nonphysical infrastructure included route maps. Route mapping required each Olli to traverse the route at a speed of 10 mph multiple times. Phase 1A route mapping took 3 weeks to complete. It included both Local Motors and Robotics Research staff to be on site. During mapping, the AV travels at 10 mph. Signs reading "Slow Moving Vehicle, Stay Back" were displayed on the vehicle. Phase 1B was mapped late in Phase 1A, which delayed Phase 1B start operations. To save time and labor, all possible routes should be mapped during the initial mapping phase.

Liability and Safety: What measures are needed to avoid property damage and physical injury? JBM-HH Safety Office reviewed and approved the route and stops. One stop was changed due to safety requirements to load and unload onto sidewalks. JBM-HH Emergency Services reviewed the Olli features and determined emergency procedures to halt operations and extinguish vehicle fires. Local Motors required riders to either go online and register to ride Olli, or to sign a paper liability waiver that provides protection to the company and notifies the rider about the privacy, liability, and legal information when they agree to ride on Olli. Children were allowed to ride with a responsible adult.

Communication: How will stakeholders impart or exchange information or news? The JBM-HH pilot held weekly synchronization meetings to insure timely communication. This created a battle rhythm that is accredited to the active and consistent stakeholder participation through the pilot.

Data: How and what data will be collected and shared? AVs have the potential to collect a lot of data. Efficient data capture, storage, and analysis is the challenge. Moreover, ERDC spent significant labor hours constructing data-sharing agreements with a variety of entities. All aspects of data require careful consideration early in the process.

2.3.2.3 Operation

The Olli AVs provided mobility service during the operation phase. For continued and successful deployment, changes and problems are continually identified and resolved.

Tools and Techniques: What processes or procedures are followed? Local Motors has a formal, 4-day steward training program that encompasses classroom, driving and autonomous operations. The 4-day safety steward training provides the basic skills for the safety steward; however, it is advised that it takes about 1 to 2 weeks of continuous operations for safety stewards to feel comfortable to operate independently. Local Motors used a minimum of one safety steward on each Olli to conduct shuttle services or demonstrations on a staggered scheduled. As Local Motors was required to collect data, safety stewards' additional tasks consisted of conducting briefings, scanning Quick Response (QR) codes or processing paper waivers, requesting surveys, tracking Olli arrival/departure times at each stop, tracking passengers getting on and off at each stop, cleaning Olli, posting/picking up 14 Olli sandwich boards at loading locations and then inputting collected data into the computer. The required number of safety stewards allocated to one Olli depends on the organization's safety level threshold or availability of safety stewards. Safety is always the first priority, so the safety steward should focus on the surrounding environment to react if required. However, in cases where there is only one safety steward per Olli, the organization must consider what other duties might be assigned to the safety steward, like examples stated above.

Performance and Monitoring: How do you ensure/measure that the effort is progressing towards the goals and objectives? ERDC constructed a user survey to inform public opinion regarding the AV pilot. ERDC additionally funded 1-2 researchers to be on site weekly observing AV operations during the entire 90-day pilot. ERDC contracted Local Motors to take careful notes regarding operation. Appendix G includes an example Weekly Report. Appendix H shows the contents of Locals Motor's Final Report.

The presence of parked cars and buses in the road would sometimes result in Olli ceasing movement until the vehicles were moved or the onboard safety steward engaged manual mode and takeovers, known as a "TKO." The frequency of these obstacles is the main cause of TKOs. Olli had a total of 138 TKOs for this deployment; however, these were not all due to vehicles blocking Olli's path. Additional reasons for TKOs throughout the deployment were construction (in two different locations); excessive braking; evading of emergency response vehicles; response to other drivers not abiding by right of way; software and hardware issues; physical damage to the vehicle; and (a few times) inclement weather (rain). Since Olli's speed capped at 12mph on a 20-25mph road and there were more frequent stops on the main road, Olli posed an inconvenience for normal traffic. Riders would either follow Olli too close or use the adjacent parking lots to speed through to get in front of Olli. These tactics did not affect Olli's operations but did provide incidents of possible safety concerns. The overall low ridership highlighted the fact that routes did not have the benefit of a formalized traffic analysis. The route did not meet the needs of the users.

2.3.2.4 Closeout

Closeout is the process of finalizing all activities for the project. For the JBM-HH pilot, this included returning the Olli AVs to Local Motors, and the ERDC task of archiving all information pertaining to the pilot.

Final Product Key Planning Question: What are the outputs and their associated transitions? Physical infrastructure associated with the AV may stay or be removed. If the infrastructure stays in place, maintenance requirements may need to be addressed. Overall lessons learned from the pilot were captured and shared publicly. ERDC and NVRC continue to share results through professional conferences and presentations. ERDC uses the data to inform other pilots and combine multiple pilot data to inform DoD policy. Local Motors and Robotic Research use results to better grow their product.

2.4 Recommendations

An after-action review meeting was held 16 October for 3 hours in person at JBM-HH. The meeting format was an informal collaborative discussion regarding successes and failures of the overall pilot. Each stakeholder group was allotted the opportunity to express their experiences and lessons learned. ERDC facilitated the meeting.

- Historically, the Federal government has approved commercial vehicle types to operate on public roads at the level of the original equipment manufacturer, while state governments have approved individual drivers as operators and licensed specific vehicles. AVs combine these into a single entity so that the issues of design, crashworthiness, licensing, and insuring have currently become ill-defined and unstandardized.

Working on other pilots with strategic partners like AASHTO, USDOT, states, and regional partners near installations will inform this ongoing process so military installations can integrate with the latest information, regulations, and priorities.
- Plan for and submit a NHTSA application as early as possible as the approval takes time; arrange with State agencies for vehicle registration and safety inspection.
- A long-term transportation plan and study is needed to "right size" the AV fleet and supporting infrastructure to meet both system goals and user objectives. This process was compressed into a very short time period and done in reverse based on available fleet and time period for the JBM-HH pilot study.
- Review current installation planning documents and policies demonstrates gaps in addressing AVs. Develop framework and guidance for future planning practices related to vehicle and fleet management, work force development, data sharing, security, legal issues, infrastructure and rights of way, and installation development considerations.

Engage with first responders and public safety officials. To ensure public safety, first responders and public safety officials (including police, fire, emergency medical services, and towing) need to have ways to interact with the AV during emergencies. Responders and safety officials will also require training to safely interact with AVs—including how to disable the vehicle, how to react if it is on fire, etc.

- Relationships and roles within the stakeholder group need to be clearly defined up front for local, state, Federal, academic, and private stakeholders. Participants ask things of others that they think are simple, but in practice may be challenging, or conversely, some hesitate to ask for fear of generating an overburdening request.
- Appropriate messaging, public engagement, and education activities to promote awareness, understanding, and acceptance of AVs, combined with an engaged champion for the effort contribute greatly to the success. Ongoing communication with AV users, potential users, and the general public to convey up-to-date information is also key to education and engagement activities.
- Workforce development impacted the project as key positions of fleet manager and safety stewards were hired during the 90-day pilot. Planning for workforce hiring, training, and integration with an ongoing AV service will help maintain good communication and timely delivery of services.

3 Infrastructure and Operations

3.1 Research focus and methods

The infrastructure and operations LOE focused primarily on the infrastructure in and around the AV that enabled it to operate, and on the details of the AV setup and operation. This work examined the interaction of the AV with the environment and the influences of the environment on the AV through both quantitative field experiments to determine if the AV successfully navigated the designated route on time, and qualitative field research supported with a record of observations. This LOE used evidence from maps, field observations, data collection, interviews, and fleet management report documentation. Units of analysis included the roadway infrastructure conditions and characteristics, speed and maneuver of the AVs, hours of operation, time schedule, number of passengers, and miles driven. The infrastructure elements of this project were most readily observed by visiting the pilot location to witness the infrastructure first hand and to see how the AV acted within the environment and with various infrastructure elements. The goal of this exploratory research was to characterize the infrastructure and operations impacts of an AV transportation service on JBM-HH.

This work attempted to answer questions such as:

- What roadway grades, conditions, or limitations prevent AV usage?
- How much space is required on the roadway, turnarounds, loading/unloading?
- What are traffic impacts to operation, loading/unloading?
- How does AV interact with signs and signals and what minimum standard is required to communicate?
- How does the AV impact Critical Infrastructure for the installation?
- What ridership levels are supported by AV (time of day, day of week, etc.)?
- What are boarding and off-boarding procedures (automated counting, security, safety)?
- How does the AV obey traffic laws (red light adherence, crosswalk management)?
- What are the vehicle parameters for object detection, classification, response (stopping distance, object classification accuracy, response suitable/acceptable)?
- How does the AV impact Continuity of Operations for the installation?

3.2 Infrastructure data and findings

The infrastructure needs of an AV are similar to that of a normal passenger vehicle. AVs need a road and must obey various traffic control devices. AVs can have difficulty navigating during periods of inclement weather due to limitations of the vehicle's sensors. As discussed previously, navigation of the AV can either depend on following a specific GPS defined route, or by using the various sensors to provide the AV with "eyes." Additionally, smart cities, or smart infrastructure along the roadway can allow the vehicle to obtain traffic condition and traffic control data wirelessly, to aid navigation. In this pilot, the AV followed a pre-programmed route based on a geo-fenced path, had no external communication while it was driving, and was slightly impaired by weather extremes.

3.2.1 Geography

Joint Base Myer-Henderson Hall is located in Arlington County, Virginia. It borders Arlington National Cemetery to the East. It is west of the Pentagon and south of the National Mall. Figures 5 and 6 show maps of the installation topography.

Figure 5. JBM-HH topography along AV route.

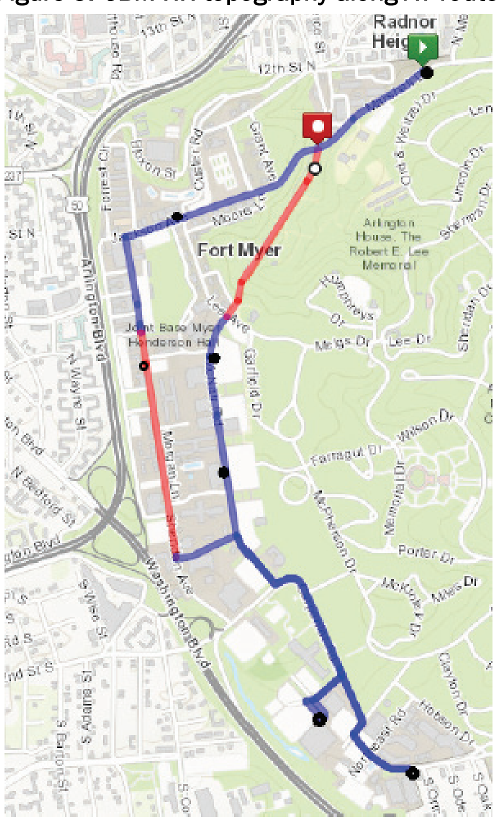


Figure 6. Topography of the JBM-HH and National Cemetery Area.

3.2.2 Roadways

All roads used by the AV were two-lane traffic with intermittent lane markings. Roads were 100% paved asphalt; however, some areas needed maintenance. The maximum observed roadway gradient was 7 degrees. All roads were considered private and under the jurisdiction of the base commander. Figure 7 shows a typical section of the main road at JBM-HH.

Figure 7. Typical roadway at JBM-HH including cracked pavement, worn lane markings, curb, and pedestrian walkways.

Street lighting was present along the AV shuttle route, but considering the AV only operated during the day, this infrastructure element was not critical to its operation.

The shuttle route contained various types of roadway signage, e.g., stop signs, speed limit signs, crosswalk signs, parking signs and other base informational signs. The highest speed limit was 25mph. Figure 8 shows several road signs along a section of the main road.

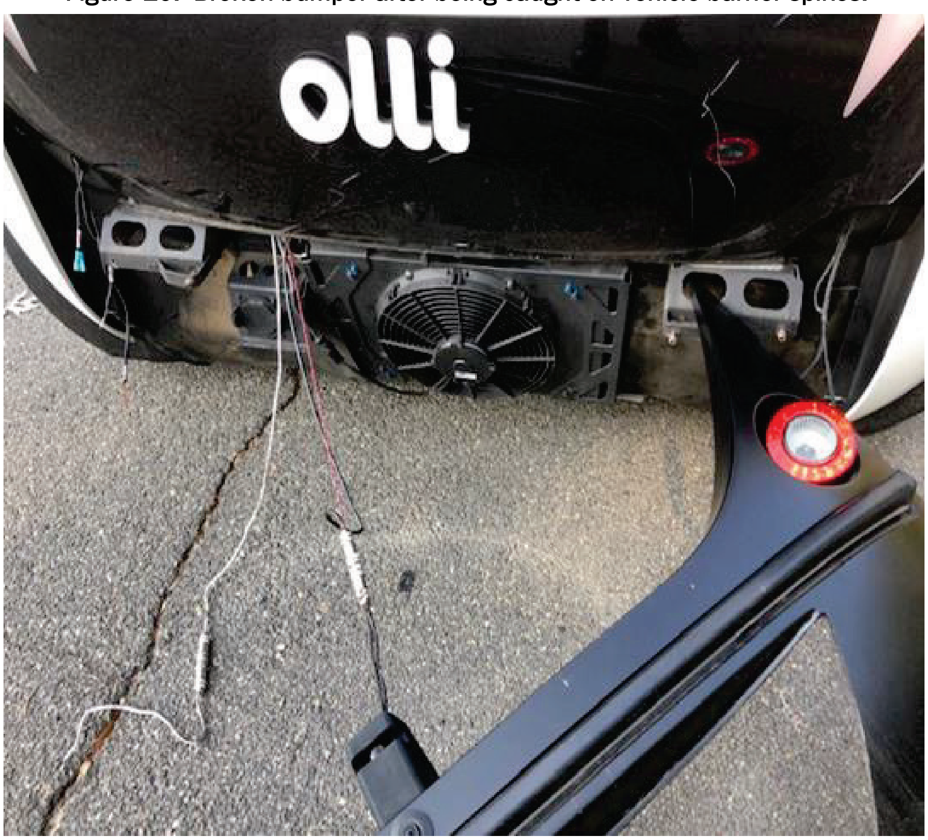
Figure 8. Signs, lampposts, and multi-use path along the AV route.

3.2.3 Traffic control signals

There were no traffic signals along the AV shuttle route. All intersections were stop sign controlled. The route required navigating 18 intersections containing stop signs. Access gates were located in close proximity to the installation hat included “tire spike” type vehicle barriers. These barriers, located in the inbound lane, prevented travel in the opposite direction. The height of these spikes exceeded 4 in., which was the minimum clearance under Olli. Thus, the spikes dragged along the underside of Olli as it proceeded over the barrier. This did not present a problem on most occurrences; only twice did it damage the Olli. One of these occasions resulted in damage to Olli rendering it inoperable for over a week. Figure 9 shows the vehicle barrier after the AV has successfully crossed over the spikes. Figure 10 shows the damage to Olli after unsuccessfully crossing the spikes.

Figure 9. Olli after crossing vehicle barrier spikes.

Figure 10. Broken bumper after being caught on vehicle barrier spikes.



3.2.4 Pedestrians

The AV shuttle route intersected several pedestrian crosswalks. The crosswalks typically had white painted lines at the location of the crosswalk. Several locations also had yellow, vertical, crosswalk signs at either side and in the middle of the street, at the location of the crosswalk. None of these infrastructure elements were problematic for the AV. Figure 11 shows the approach to a typical pedestrian crossing.

Figure 11. Crosswalk intersecting AV Shuttle route.

3.2.5 Connectivity

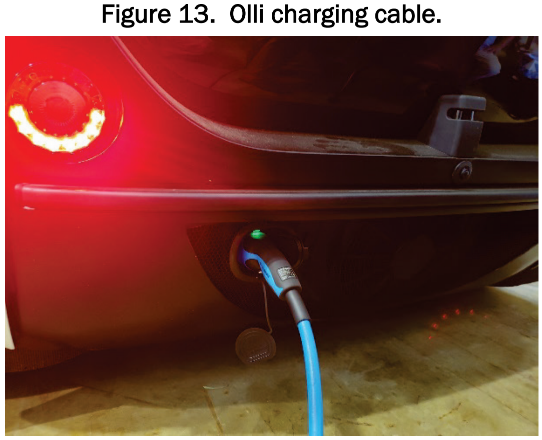
To ensure GPS accuracy of the AV during operation, an RTK antenna was temporarily installed. The RTK base station's sole purpose is to receive a strong GPS signal to provide RTK corrections to the vehicle. The chosen location was Brucker Hall (the Band Building), which is a central rooftop on the installation. Figure 12 shows the RTK transmitter on top of the building. Requirements for the location included: a clear view of the sky, especially at 15 degrees above the horizon, and good cell coverage to transmit RTK corrections.

Figure 12. RTK transmitter on rooftop.

3.2.6 Vehicle charging and storage

Only one compatible and high-speed charging station was available for the two AVs on JBM-HH. The installation purchased this station before the project and located in the AV storage garage. The garage was located in close proximity to the shuttle route and was large enough to park both AVs. However, the AVs did have to exit the garage to fully engage GPS during the booting procedure. Outdoor parking was available for this step at the garage location. Figure 13 shows Olli plugged into the charging cable.

Figure 13. Olli charging cable.



3.3 Operations data and findings

3.3.1 Deployment and setup

Deployment of the Olli at JBM-HH included arrival of Olli #10 and #13, charging station installation, and setup of the RTK base station. These tasks were completed in approximately 3 weeks.

3.3.2 Olli® 1.0 specifications

Both Olli 10 and 13 at JBM-HH were version 1.0. An Olli 1.0 is equipped with multiple sensors, which included six LiDAR, five radar, six cameras, and two GPS units. Olli has a maximum speed of 25mph, but for this pilot, Olli traveled at no more than 12mph. Approximately 20% of the Olli body was 3D printed from Electrofil carbon fiber reinforced plastic (Figure 14). Other parts of the structure were made from steel tubing and aluminum. The total weight of the vehicle was 5850 pounds. Maximum ground clearance was 4.5 in. when unloaded (Figure 15). Figure 16 shows the Olli vehicle specifications.

Figure 14. 3D printed fender.

Figure 15. Olli ground clearance was approximately 4 in.

Figure 16. Olli 1.0 specifications.

DRIVETRAIN

Transmission	9.59:1 Gear Ratio

SENSORS

LiDAR	3x 3D Velodyne, 3x 2D Hokuyo
Radar	4x SRR2, 1x Fwd ESR
Internal Measurement Unit	Yes
Optical Camera	6x HD CCTV
Bumper Switch	Front, Rear
GPS	2 GPS Antennas

COMMUNICATION / DATA

GSM/LTE Modem
On-Board Data Recorder

HVAC CONTROLLER

Heating/Air Conditioning Standard

DIMENSIONS

Length	3920mm (12.86ft)
Width	2050mm (6.73ft)
Height	2500mm (8.20ft)
Wheelbase	2526mm (8.29ft)
Passenger Room Height	1950mm (6.40ft)
Turning Circle	Curb to Curb: 6m (19.7ft)

RANGE

Average Range	56km/35mi (Nominal) 32km/20mi (Max Load, Max AC)

CAPACITY

Max Passengers	Up to 8*

*Capacity varies based on regulatory restrictions and seating layout.

MOTOR

Max Torque	240Nm
Continuous Torque	125Nm
Max Power	100kW
Continuous Power	30kW
Max Speed	40km/h (25mph)
Type	Brushless Synchronous AC

POWER SYSTEM

Max Capacity (kWh)	18.5 Max (16.2 Usable)
Charger Type	Up to 22kW A/C
Charge Time (440V 32A A/C, 3-Phase)	Approx. 1 Hour**

**Charge time indicative of 3 phase mains power. Single phase mains power will be approximately 4 hours.

WEIGHT

GVWR	2654 kg (5850 lbs)
Carrying Capacity	612 kg (1350lbs)

CHASSIS / SUSPENSION / BRAKES

Chassis	Aluminum
Front Suspension	Macpherson
Rear Suspension	Macpherson
Front Brakes	Disc
Rear Brakes	Disc
Front Tire	215/50/R17
Rear Tire	215/50/R17
Emergency Brake	Yes

For navigation, Olli employed three LiDAR sensors, four radar sensors, six optical cameras, and two GPS antennas. The data from these navigation sensors were independent of the vehicle telemetry data such as speed, braking, and battery charge. The separation of data feeds is a function of the fact that the Olli design was the result of a collaboration between two different companies, Local Motors, Inc. (a custom innovative vehicle company) and Robotic Research, LLC (a robotics and automated technology company); the Olli vehicle combines expertise from both partners. Figures 17 and 18 show the exterior locations of these sensors. Table 2 lists the names and data formats for each sensor.

Figure 17. Bumper mounted Radar (top), camera (middle), LiDAR (bottom).

Figure 18. Roof mounted optical camera (left) and LiDAR (right).

Table 2. Olli sensors, locations, formats, and datasets.

Item	Description
Cameras	Locations: exterior front_top, front_bottom, left, right, back_bottom, inside cabin
	H264 video in PCAP (packet capture) format - a tcpdump on camera eth interface
	Can be converted to mp4 using Linux-based pcap_to_mp4 utility
Hokuyos LiDAR	Locations: exterior rback_right, back_center, back_left
	PCAP format - just a tcpdump on hokuyo eth interface
Velodynes LiDAR	Locations: exterior front_lower, front_upper, rear_upper
	PCAP format - a tcpdump on vlp16 eth interface
SRR2 Radar	Locations: front, rear
	PCAP format - raw CAN messages stored in PCAP file
Delphi Radar	PCAP format - raw CAN messages stored in PCAP file
Deployment general requested data	CSV file univBuffalo.general - first line of the file gives the description of what is in each column
	Columns are: gmtSeconds, vcuState, batteryPercentage, commandedTorque, actualTorque, commandedBrakePressure, actualBrakePressure
Deployment trajectory requested data	CSV file format- univBuffalo_trajectory - each data entry is three lines • 1st line in set = gmtSeconds • 2nd line in set = northing points of trajectory - if this and the 3rd line are empty there is no trajectory • 3rd line in set = easting points of trajectory - if this and the 2nd line are empty there is no trajectory • trajectories end at stops

Appendix I contains raw data format for Robotics Research datasets, and Appendix J contains example data returned from the Local Motors API endpoint.

3.3.3 Mapping

Before passenger operations, Olli conducted mapping of the planned route(s) by collecting data from the sensors while navigating the route. The mapping was completed over a period of 3 weeks. This phase was referred to as "pre-planning and deployment operations," which included site surveys and data collection of infrastructure and route. Figure 19 shows a map of JBM-HH overlaid with the GPS location from Olli 13 during the mapping. This figure shows where the Olli traveled during the mapping phase, which encompassed more than the final route. Figure 20 shows the "map" generated by the Olli LiDAR. This figure gives a good visual representation of the extent of the LiDAR range and subsequent field of view.

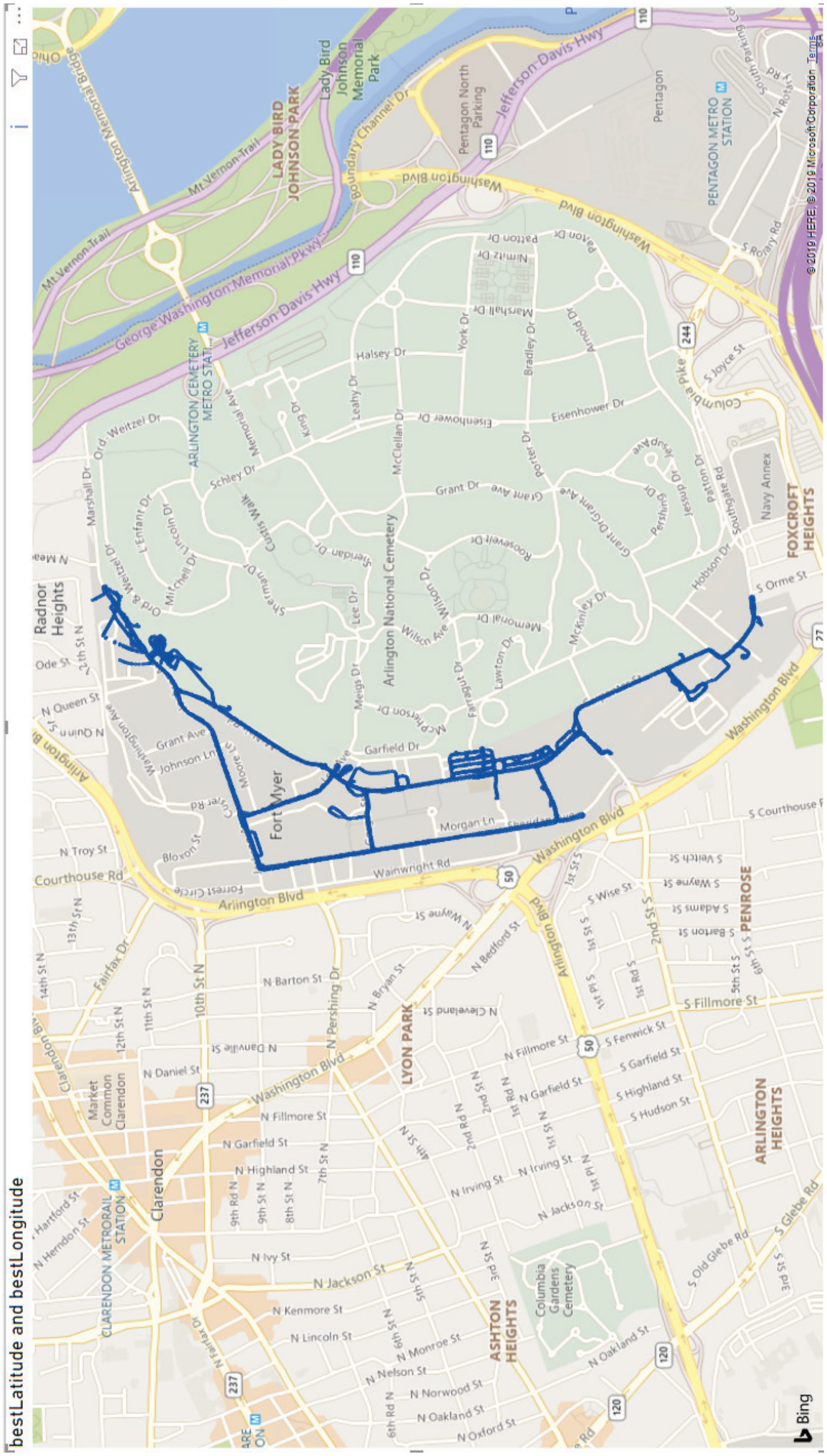
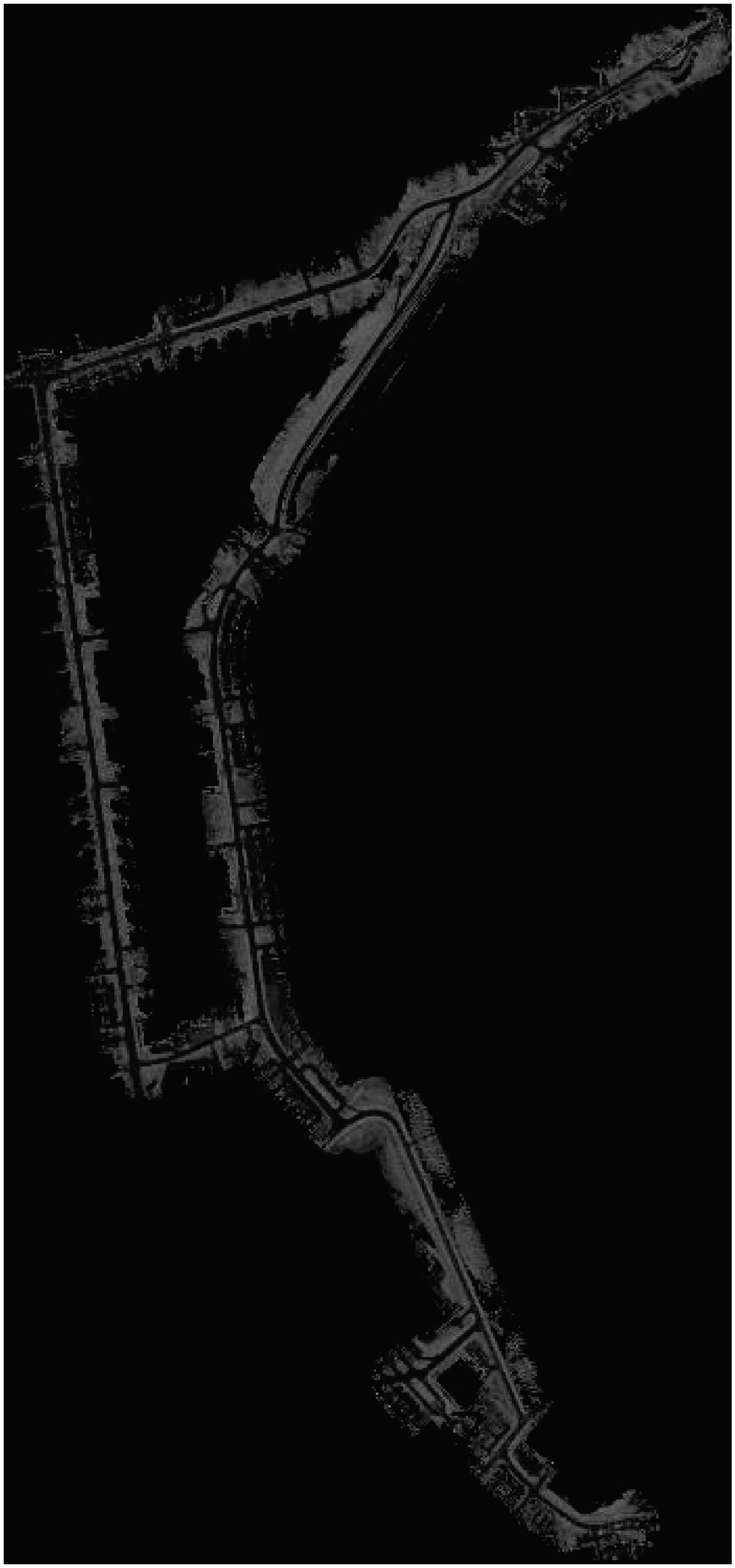


Figure 19. Olli 13 GPS data overlaid on street map.

Figure 20. Overview of the mapped route showing the extent of the LiDAR field of view.



3.3.4 Routes

The Phase 1a route, commonly known as the “short route” measured 0.9 miles with four right turns, three stop signs, and three programmed stops. The route is highlighted in magenta in Figure 21. Olli traveled this route for a total of 83.7 operational miles with an average success rate of 97 % (the percentage of passenger stops completed versus planned). Even though Olli shared the road with the public, its performance blended in with regular traffic; other vehicles did not present any issues or interfere with the AV. The success of this phase provided the opportunity to transition to Phase 1b of the deployment.

Phase 1b, also known as the long route, measured approximately 4.4 miles, and is currently the longest and most intricate route operated by Olli to date. This route is highlighted in blue in Figure 21. The route that was planned and later mapped included two vehicle barriers, 7% grade road, 18 stop signs, 10 crosswalks, various intersection layouts, and 14 programmed stops. Some of the programmed stops were located in the middle of crosswalks, which proved problematic for some pedestrians. Olli traveled a total of 872.6 operational miles with a 95% success rate (percentage of passenger stops completed versus planned during this phase).

Base traffic was intermittently impacted by Olli, resulting in queues forming behind Olli. Contributing factors included the AV’s maximum speed of 12 mph, numerous shuttle stop locations, and two-lane roads with curb and gutter on each side, which limited pull-out locations for the AV. During the fixed route operation, this restricted the ability of other vehicles to pass the AV during passenger loading/unloading. Furthermore, procedures required Olli to wait at the fixed shuttle stop locations until the designated departure time if it was ahead of schedule.

3.3.5 Safety onboard Olli®

As discussed in chapter 2, the installation fire and emergency services received information on the AV and its unique characteristics to allow them to plan for any safety-related incidents of fire, crash, or injury. Olli is a completely electric vehicle and carried no petroleum-based liquids on board. The safety steward was available for passenger questions and during invitational events gave a safety and overview brief to the groups before they boarded the vehicle.

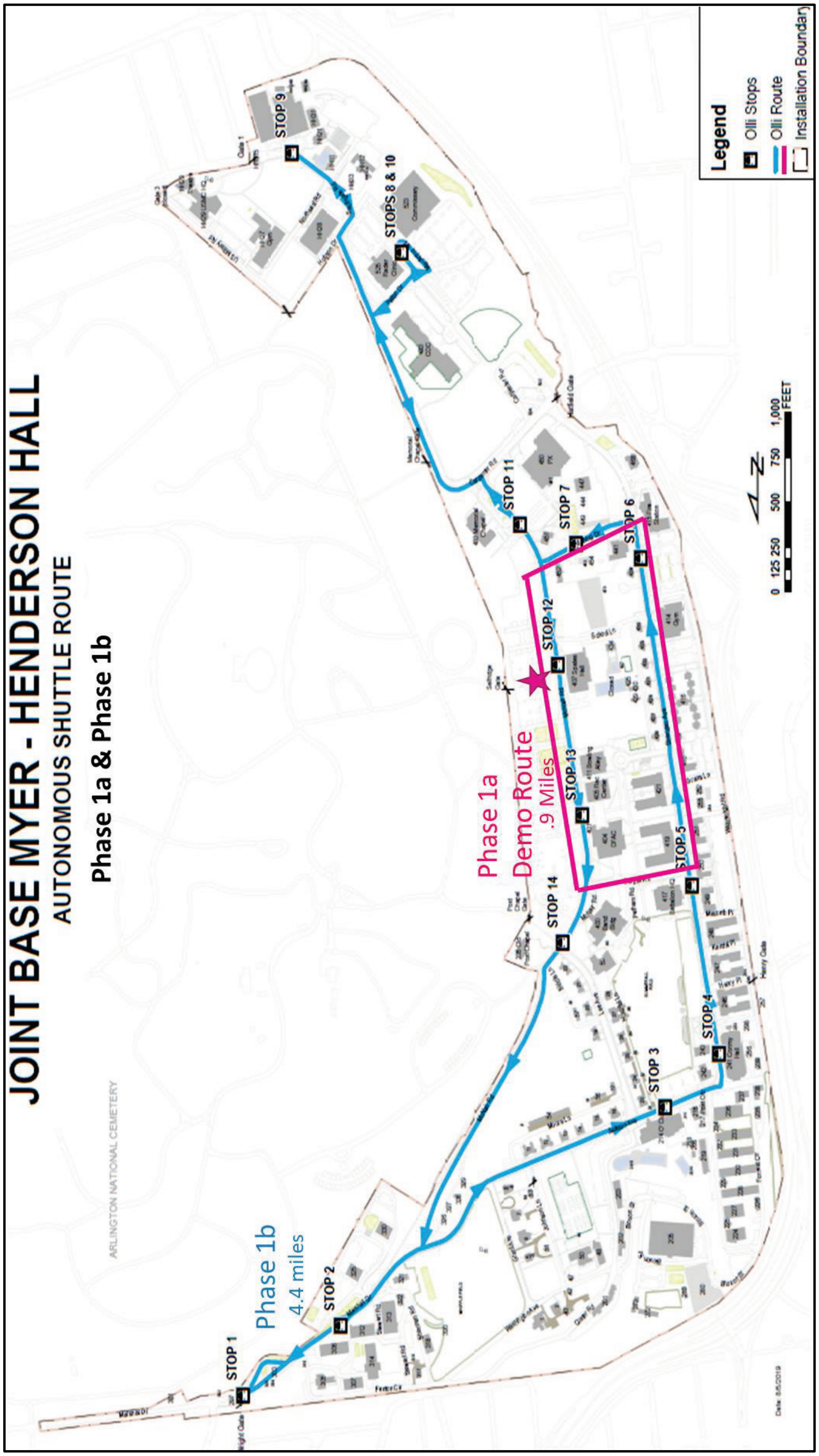


Figure 21. Phase 1A and 1B shuttle routes on JBM-HH.

During all Olli engagements, a safety steward stood at the controls, either operating the Olli in manual mode, or observing while Olli operated in autonomous mode. Safety was paramount in the operations; therefore, safety stewards would err on the side of caution to take over in any potentially unsafe situation. At each Olli stop, the safety steward engaged the handbrake before opening the door to board passengers. After closing the door and releasing the handbrake, the steward gave Olli a manual computer input for the Olli to continue to the next stop.

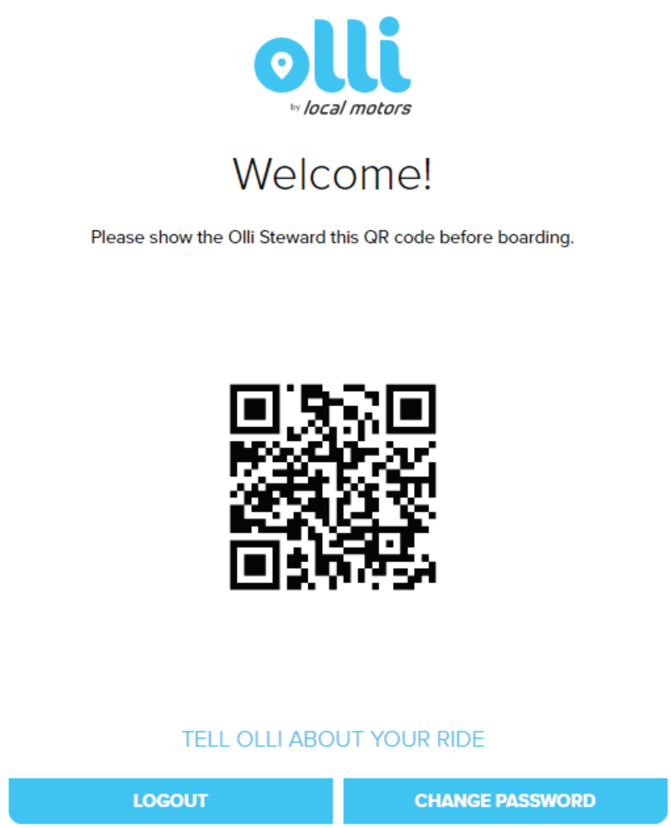
The Olli 1.0 was capable of carrying eight passengers, including the steward. During this pilot, all passengers were required to sit in the designated area and to use seatbelts when the Olli was underway. The rear of the vehicle displayed a sign warning other vehicles that the Olli was an AV (Figure 22). Before riding the Olli, passengers were required to sign a waiver (either digital or hardcopy). The digital version could be accessed from a rider's smartphone (found at www.rideolli.com) and the hardcopy was available onboard the Olli. If completed digitally, the steward would scan the rider's barcode on boarding (Figure 23). The website has one link that will take the user to a survey to be completed after one's ride. The app does not contain the functionality to determine the location of Olli, or what time it is expected to arrive at any particular stop. Nor does it have the ability to tell Olli where to pick up a passenger for point-to-point service. These useful tools were not available in this pilot but are planned in future versions of Olli.

The Olli made complete stops at all planned stop locations. The doors were not opened unless passengers were waiting to board, or passengers needed to exit. The steward recorded the exact time of arrival and departure of all stops along the route. When the Olli became ahead of schedule, the steward sometimes chose to wait at the stop until the scheduled time of departure.

Since Olli's speed capped at 12mph on a 20-25mph road and there were more frequent stops on the main road, Olli posed an inconvenience for normal traffic. Riders would either follow Olli too close or, occasionally, would speed through an adjacent parking lot to get ahead of Olli. These tactics did not affect Olli's operations but did provide possible safety concerns.

Figure 22. Warning signage at the rear of the Olli.

Figure 23. After signing the wavier, the rider obtained a QR code necessary for boarding.



3.3.6 Takeovers

The presence of parked cars and buses in the road would sometimes result in Olli ceasing movement until the vehicle moved out of the way or the onboard safety steward engaged Olli's manual mode in a TKO. The frequency of these obstacles was the main cause of TKOs. Olli had a total of 138 TKOs for this deployment; however, these were not all due to vehicles blocking Olli's path. Other reasons for TKOs throughout the deployment were construction (in two different locations); excessive braking (by Olli during autonomous mode); evading of emergency response vehicles; in response to other drivers who were not abiding by right of way conventions; software and hardware issues; physical damage to the vehicle; and a few times, due to inclement weather (rain). The dates and reasons for each TKO are documented in the weekly fleet operations reports from Local Motors (see an example in Appendix G).

3.3.7 Advertising

The *Pentagram*, a print newspaper, included periodic news of the Olli deployment at JBM-HH (Appendix D). At times, the Olli route map and stop schedule was also printed in the newspaper. Other electronic means were used to advertise the Olli's operation, including the electronic newsletter. During Phase 1b of the deployment, "Olli Stop" signs were placed at each of the planned stop locations (see Figure 24). The small plastic billboard displayed information to indicate that was the location to board the Olli. A collection of route maps and schedules were attached to the billboard.

During the third to the last week in Phase 1b, the bowling alley began displaying Olli route and schedule information on their café tables. The information included both instructions for registering online and the Olli daily schedule. Figures 25 and 26 show the digital marketing materials and schedule. The human factors LOE discusses the impact of these promotional efforts.

Figure 24. Example of Olli Stop sandwich boards located adjacent to each stop at JBM-HH.

Figure 25. Olli marketing materials.

Please Register Online
Before
You Ride And Have Your
QR Code Ready to Scan

Please Go Back To
RideOlli.com
And
Complete A Survey
After Your Ride
Thank You

For Updates Please Check JBMHH Website
https://home.army.mil/jbmhh/

Times Subject to Change
If Olli doesn't arrive within 10mins assume Olli isn't running.
Olli does not run in heavy rain.

JBMHH Olli Bus Schedule

3-6 September (Bus 1 & Bus 2)
9-13 September (Bus A, Bus 1 & Bus 2)
16-20 September (Bus 1 & Bus 2, Bus Z)
23-27 September (Bus 1 & Bus 2, Bus Z)

JOINT BASE MYERS HENDERSON HALL OLLI SHUTTLE BUS SCHEDULE
DATES AND TIMES WEEKLY SCHEDULE VARIES ALWAYS CHECK OLLI CALENDAR

BUS A (Morning)			BUS 1 (Lunch)			BUS 2 (Lunch)			BUS Z (Evening)		
STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL
Stop #1	Wright Gate	7:30 AM	Stop #1	Wright Gate	11:00 AM	Stop #1	Wright Gate	11:20 AM	Stop #1	Wright Gate	2:30 PM
Stop #2	Motor Pool	7:32 AM	Stop #2	Motor Pool	11:02 AM	Stop #2	Motor Pool	11:22 AM	Stop #2	Motor Pool	2:32 PM
Stop #3	Patton Hall	7:35 AM	Stop #3	Patton Hall	11:05 AM	Stop #3	Patton Hall	11:25 AM	Stop #3	Patton Hall	2:35 PM
Stop #4	Conmy Hall	7:37 AM	Stop #4	Conmy Hall	11:07 AM	Stop #4	Conmy Hall	11:27 AM	Stop #4	Conmy Hall	2:37 PM
Stop #5	Library	7:39 AM	Stop #5	Library	11:09 AM	Stop #5	Library	11:29 AM	Stop #5	Library	2:39 PM
Stop #6	Shoppette	7:43 AM	Stop #6	Shoppette	11:13 AM	Stop #6	Shoppette	11:33 AM	Stop #6	Shoppette	2:43 PM
Stop #7	Post Exchange	7:45 AM	Stop #7	Post Exchange	11:15 AM	Stop #7	Post Exchange	11:35 AM	Stop #7	Post Exchange	2:45 PM
Stop #8	Commissary	7:50 AM	Stop #8	Commissary	11:20 AM	Stop #8	Commissary	11:40 AM	Stop #8	Commissary	2:50 PM
Stop #9	South Gate	7:53 AM	Stop #9	South Gate	11:23 AM	Stop #9	South Gate	11:43 AM	Stop #9	South Gate	2:53 PM
Stop #10	Commissary	7:59 AM	Stop #10	Commissary	11:29 AM	Stop #10	Commissary	11:49 AM	Stop #10	Commissary	2:59 PM
Stop #11	Memorial Chapel	8:03 AM	Stop #11	Memorial Chapel	11:33 AM	Stop #11	Memorial Chapel	11:53 AM	Stop #11	Memorial Chapel	3:03 PM
Stop #12	Spates	8:06 AM	Stop #12	Spates	11:36 AM	Stop #12	Spates	11:56 AM	Stop #12	Spates	3:06 PM
Stop #13	Dining Hall	8:07 AM	Stop #13	Dining Hall	11:37 AM	Stop #13	Dining Hall	11:57 AM	Stop #13	Dining Hall	3:07 PM
Stop #14	Old Post Chapel	8:09 AM	Stop #14	Old Post Chapel	11:39 AM	Stop #14	Old Post Chapel	11:59 AM	Stop #14	Old Post Chapel	3:09 PM
Stop #1	Wright Gate	8:14 AM	Stop #1	Wright Gate	11:44 AM	Stop #1	Wright Gate	12:04 PM	Stop #1	Wright Gate	3:14 PM
Stop #2	Motor Pool	8:16 AM	Stop #2	Motor Pool	11:46 AM	Stop #2	Motor Pool	12:06 PM	Stop #2	Motor Pool	3:16 PM
Stop #3	Patton Hall	8:19 AM	Stop #3	Patton Hall	11:49 AM	Stop #3	Patton Hall	12:09 PM	Stop #3	Patton Hall	3:19 PM
Stop #4	Conmy Hall	8:21 AM	Stop #4	Conmy Hall	11:51 AM	Stop #4	Conmy Hall	12:11 PM	Stop #4	Conmy Hall	3:21 PM
Stop #5	Library	8:23 AM	Stop #5	Library	11:53 AM	Stop #5	Library	12:13 PM	Stop #5	Library	3:23 PM
Stop #6	Shoppette	8:27 AM	Stop #6	Shoppette	11:57 AM	Stop #6	Shoppette	12:17 PM	Stop #6	Shoppette	3:27 PM
Stop #7	Post Exchange	8:29 AM	Stop #7	Post Exchange	11:59 AM	Stop #7	Post Exchange	12:19 PM	Stop #7	Post Exchange	3:29 PM
Stop #8	Commissary	8:34 AM	Stop #8	Commissary	12:04 PM	Stop #8	Commissary	12:24 PM	Stop #8	Commissary	3:34 PM
Stop #9	South Gate	8:37 AM	Stop #9	South Gate	12:07 PM	Stop #9	South Gate	12:27 PM	Stop #9	South Gate	3:37 PM
Stop #10	Commissary	8:43 AM	Stop #10	Commissary	12:13 PM	Stop #10	Commissary	12:33 PM	Stop #10	Commissary	3:43 PM
Stop #11	Memorial Chapel	8:47 AM	Stop #11	Memorial Chapel	12:17 PM	Stop #11	Memorial Chapel	12:37 PM	Stop #11	Memorial Chapel	3:47 PM
Stop #12	Spates	8:50 AM	Stop #12	Spates	12:20 PM	Stop #12	Spates	12:40 PM	Stop #12	Spates	3:50 PM
Stop #13	Dining Hall	8:51 AM	Stop #13	Dining Hall	12:21 PM	Stop #13	Dining Hall	12:41 PM	Stop #13	Dining Hall	3:51 PM
Stop #14	Old Post Chapel	8:53 AM	Stop #14	Old Post Chapel	12:23 PM	Stop #14	Old Post Chapel	12:43 PM	Stop #14	Old Post Chapel	3:53 PM
END	Wright Gate	8:58 AM	END	Wright Gate	12:28 PM	END	Wright Gate	12:48 PM	END	Wright Gate	3:58 PM

local motors

Figure 26. Olli Bus Schedule for September.

JOINT BASE MYERS HENDERSON HALL OLLI SHUTTLE BUS SCHEDULE DATES AND TIMES WEEKLY SCHEDULE VARIES ALWAYS CHECK OLLI CALENDAR											
BUS A (Morning)			BUS 1 (Lunch)			BUS 2 (Lunch)			BUS Z (Evening)		
STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL	STOPS	LOCATION	ARRIVAL
Stop #1	Wright Gate	7:30 AM	Stop #1	Wright Gate	11:00 AM	Stop #1	Wright Gate	11:20 AM	Stop #1	Wright Gate	2:30 PM
Stop #2	Motor Pool	7:32 AM	Stop #2	Motor Pool	11:02 AM	Stop #2	Motor Pool	11:22 AM	Stop #2	Motor Pool	2:32 PM
Stop #3	Patton Hall	7:35 AM	Stop #3	Patton Hall	11:05 AM	Stop #3	Patton Hall	11:25 AM	Stop #3	Patton Hall	2:35 PM
Stop #4	Conmy Hall	7:37 AM	Stop #4	Conmy Hall	11:07 AM	Stop #4	Conmy Hall	11:27 AM	Stop #4	Conmy Hall	2:37 PM
Stop #5	Library	7:39 AM	Stop #5	Library	11:09 AM	Stop #5	Library	11:29 AM	Stop #5	Library	2:39 PM
Stop #6	Shoppette	7:43 AM	Stop #6	Shoppette	11:13 AM	Stop #6	Shoppette	11:33 AM	Stop #6	Shoppette	2:43 PM
Stop #7	Post Exchange	7:45 AM	Stop #7	Post Exchange	11:15 AM	Stop #7	Post Exchange	11:35 AM	Stop #7	Post Exchange	2:45 PM
Stop #8	Commissary	7:50 AM	Stop #8	Commissary	11:20 AM	Stop #8	Commissary	11:40 AM	Stop #8	Commissary	2:50 PM
Stop #9	South Gate	7:53 AM	Stop #9	South Gate	11:23 AM	Stop #9	South Gate	11:43 AM	Stop #9	South Gate	2:53 PM
Stop #10	Commissary	7:59 AM	Stop #10	Commissary	11:29 AM	Stop #10	Commissary	11:49 AM	Stop #10	Commissary	2:59 PM
Stop #11	Memorial Chapel	8:03 AM	Stop #11	Memorial Chapel	11:33 AM	Stop #11	Memorial Chapel	11:53 AM	Stop #11	Memorial Chapel	3:03 PM
Stop #12	Spates	8:06 AM	Stop #12	Spates	11:36 AM	Stop #12	Spates	11:56 AM	Stop #12	Spates	3:06 PM
Stop #13	Dining Hall	8:07 AM	Stop #13	Dining Hall	11:37 AM	Stop #13	Dining Hall	11:57 AM	Stop #13	Dining Hall	3:07 PM
Stop #14	Old Post Chapel	8:09 AM	Stop #14	Old Post Chapel	11:39 AM	Stop #14	Old Post Chapel	11:59 AM	Stop #14	Old Post Chapel	3:09 PM
Stop #1	Wright Gate	8:14 AM	Stop #1	Wright Gate	11:44 AM	Stop #1	Wright Gate	12:04 PM	Stop #1	Wright Gate	3:14 PM
Stop #2	Motor Pool	8:16 AM	Stop #2	Motor Pool	11:46 AM	Stop #2	Motor Pool	12:06 PM	Stop #2	Motor Pool	3:16 PM
Stop #3	Patton Hall	8:19 AM	Stop #3	Patton Hall	11:49 AM	Stop #3	Patton Hall	12:09 PM	Stop #3	Patton Hall	3:19 PM
Stop #4	Conmy Hall	8:21 AM	Stop #4	Conmy Hall	11:51 AM	Stop #4	Conmy Hall	12:11 PM	Stop #4	Conmy Hall	3:21 PM
Stop #5	Library	8:23 AM	Stop #5	Library	11:53 AM	Stop #5	Library	12:13 PM	Stop #5	Library	3:23 PM
Stop #6	Shoppette	8:27 AM	Stop #6	Shoppette	11:57 AM	Stop #6	Shoppette	12:17 PM	Stop #6	Shoppette	3:27 PM
Stop #7	Post Exchange	8:29 AM	Stop #7	Post Exchange	11:59 AM	Stop #7	Post Exchange	12:19 PM	Stop #7	Post Exchange	3:29 PM
Stop #8	Commissary	8:34 AM	Stop #8	Commissary	12:04 PM	Stop #8	Commissary	12:24 PM	Stop #8	Commissary	3:34 PM
Stop #9	South Gate	8:37 AM	Stop #9	South Gate	12:07 PM	Stop #9	South Gate	12:27 PM	Stop #9	South Gate	3:37 PM
Stop #10	Commissary	8:43 AM	Stop #10	Commissary	12:13 PM	Stop #10	Commissary	12:33 PM	Stop #10	Commissary	3:43 PM
Stop #11	Memorial Chapel	8:47 AM	Stop #11	Memorial Chapel	12:17 PM	Stop #11	Memorial Chapel	12:37 PM	Stop #11	Memorial Chapel	3:47 PM
Stop #12	Spates	8:50 AM	Stop #12	Spates	12:20 PM	Stop #12	Spates	12:40 PM	Stop #12	Spates	3:50 PM
Stop #13	Dining Hall	8:51 AM	Stop #13	Dining Hall	12:21 PM	Stop #13	Dining Hall	12:41 PM	Stop #13	Dining Hall	3:51 PM
Stop #14	Old Post Chapel	8:53 AM	Stop #14	Old Post Chapel	12:23 PM	Stop #14	Old Post Chapel	12:43 PM	Stop #14	Old Post Chapel	3:53 PM
END	Wright Gate	8:58 AM	END	Wright Gate	12:28 PM	END	Wright Gate	12:48 PM	END	Wright Gate	3:58 PM

3.3.8 Weather

Operation of the AV was constrained by weather and climate. During this pilot, rain caused operations to stop due to safety concerns over sensor reliability and wheel slippage. However, the manufacturer stated that the AV can operate in the rain. In fact, it is not the rain itself that affects the sensors, but the large puddles that collect after a hard or long rain. These puddles affect the sensor's ability to "see" the road due to reflecting light that impacts LiDAR. Also, high daytime temperatures and continuous running of air-conditioning during this pilot study resulted in increased battery use.

3.3.9 Data collection

The vehicle's sensor data were stored in a hard drive connected to the Olli during operation. Each night, this hard drive was removed from the Olli, and data were uploaded automatically for storage and retrieval. Local Motors provided access through an application programming interface (API) to the data approximately 69 days into the pilot. However, because the data were only held on the API for a limited time, some initial data were lost before gaining access.

In addition, some problems were experienced with the hard drive during the course of the pilot. The hard drive was located above, on the Olli ceiling (Figure 27). However, sometimes the Velcro failed, resulting in faulty hard drive operation.

Figure 27. The Velcro patch that secured the hard drive to the ceiling.

In addition to the sensor data, safety stewards manually recorded the miles traveled, number of passengers, number of takeovers, and operation time for each mission. Figure 28 shows the aggregated data for these metrics. Of note are the ~1000 total miles, ~400 riders, 138 takeovers, and ~8,900 service minutes accumulated during this pilot.

Figure 28. Aggregated safety steward data recorded for all Olli Missions.

3. Encl C_Tab 0_Final Overall_JBMHH Olli Dat

Month	Week	Guest	Route Phase 1a (Short) Mileage	Route Phase 1b (Long)	Total Mileage	Rider Count	Manual Takeovers (TKOs)	Operational Time (Minutes)	Operational Downtime (Minutes)
July	Week 1 (8-12)	- DFMWR - FFX County - DPW/HQ/EEO - EPA - STUDENTS	4.5	0	4.5	46			
July	Week 2 (15-19)	- CDR MG Banta - KAUST - NVRC - CMC Town Hall - CMC Town Hall - DPW/DES/NEC	3.6	0	3.6	31			
July	Week 3 (22-26)	- NVTC - Pentagon	1.8	26.4	28.2	30			
July	Week 4 (29-31)	- AARP - IN-Q-Tel - Twighlight Tatoo	1.8	17.6	19.4	64			
August	Week 5 (5-9)	- LM Shuttle Service - COC Shuttle - ITE	3.6	52.8	56.4	22	1	380	0
August	Week 6 (12-16)	- LM Shuttle Service - VDOT - Public Affairs - MG McGuire	3.1	82.5	85.6	21	6	780	30
August	Week 7 (19-23)	- NVRC Guest	0	117.1	117.1	20	13	886	480
August	Week 8 (26-30)	- LM Shuttle Service - Child Development Services	2.7	118.7	121.4	29	36	1,680	660
September	Week 9 (3-6)	- LM Shuttle Service - Booze Allen - Loudoun County	5	76.8	81.8	26	17	970	240
September	Week 10 (9-13)	- LM Shuttle Service - Dominion Power - GMU	3.6	128	131.6	35	18	1,311	96
September	Week 11 (16-20)	- LM Shuttle Service - Alexandria County	0	108.4	108.4	30	32	1,165	210
September	Week 12 (23-27)	- LM Shuttle Service - USDOT	54	144.3	198.3	47	15	1,739	0
		TOTAL	83.7	872.6	956.3	401	138	8,911	1,716

3.3.10 Permitting

Olli does not have permitting in the state of Virginia, but due to the nature of operations on an Army Installation, use of AVs is controlled by the base commander. Olli does have permitting by the Maryland Department of Transportation to operate on Maryland public roads. More details on Federal, state, and local regulations and requirements were included in the planning and programming LOE.

3.4 Results and recommendations

The following recommendations and key results are based on the infrastructure and operations LOE. It is important to recognize that these are based on a single case study deployment of a single AV type on one military installation during the predominantly warmer summer months in eastern Virginia, USA. However, many of the findings were generalizable into these key considerations.

- Existing road and roadside infrastructure was adequate for AV deployment; no major investments were required to improve or change current system at JBM-HH before the pilot. All roads were two-lane traffic and all intersections were stop sign controlled. An RDK (reference design kit) antenna was provided by the contractor and temporarily installed on top of a building during the deployment to ensure GPS accuracy of the AV during operation. Minimum roadway modification is preferred. Identify the needed new signage, marking changes, and signal technology upgrades (e.g., Connected technology, Transit Signal Priority) early on to allow time for design and installation.
- Mapping and establishment of the base route took 3 weeks of AV onsite preparation. Additional routes were not added later in the project due to the cost and resources required to bring back the mapping team. (The installation originally planned to accomplish this task in only w days.) Consider if mapping can be done in advance (including optional routes) or develop standards and specifications for installation to deliver this to AV providers. Also, select the route(s) for fulfilling clear purposes such as demo/research, first and last mile, serving origin/destination needs.
- Traffic operations were sometimes impacted by the AV maximum speed of 12 mph, which caused queues to form behind the AV. Numerous shuttle stop locations and two-lane roads with curb and gutter on each side restricted pull-out locations for the AV during fixed route

operation, which in turn limited the ability of other vehicles to pass the AV during loading/unloading of passengers. Planned shuttle stops would preferably allow the AV to pull over and stop for loading/unloading without impacting normal traffic operations.

- Sufficient quantity, type, and location of electric-powered vehicle charging stations is critical for infrastructure and fleet management planning. One compatible and high-speed charger was available for the two Olli AVs on JBM-HH. The installation purchased this charger before the project and located it in the AV storage garage.
- Operation of the AV was constrained by inclement weather and darkness. Rain caused operations to halt due to safety concerns over sensor reliability and wheel slippage. Heating and air-conditioning caused increased battery usage. Operation was restricted to daylight hours during the summer, but it is anticipated that operation in cold weather or darkness would increase battery usage for heating and lighting.
- Determine restrictions that impact AV operation ahead of time (e.g., rider's age, Americans with Disabilities Act [ADA] requirement, weather and condition constrains). By law, state and local public transportation agencies require the accommodation of all passengers with disabilities.
- Establish standard operating procedure for safety steward and incident responders in the event of an emergency or weather event. For example, if inclement weather does occur in the middle of a route, the safety steward needs to know what to do with current passengers. Asking them to exit the vehicle there or at the next stop could leave them stranded far from other transportation options. However, continuing to operate with the passengers on board could lead to other safety concerns. The pilot at JBM-HH operated in relatively calm months of late summer, but other deployments may face significantly worse weather during operation.
- Ensure that emergency incidents that impact AV shuttle operation are accounted for (e.g., emergency vehicle approaching that requires AV to yield).
- Operation of AV may be constrained by environmental conditions. Examples during this pilot study included "unlearned" scenarios of road construction, parked buses, or incidents requiring off-tracking from geo-fenced and mapped areas. Grades steeper that 7% from Wright Gate to Stop #3 increased battery usage and slowed the AV, challenging its climbing and maneuver capability. Navigating over steel spike security strips used at both Wright Gate and South Gate resulted in damage to one AV, rendering it inoperable for 1 week. Typical ground

clearance of the Olli with passengers was 4 in.; for military installation applications, this clearance should be higher (similar to standard highway automobiles).

- The AV operations team required a designated work space for team meetings, vehicle and tool storage and maintenance, data download, and standard office functions. The installation maintenance bay provided to the AV team was mostly adequate for the pilot, except for data transmission that occurred offsite. Ideally, high-speed internet or 5G access along with a more robust office setting sized for the AV fleet and team would be incorporated into the AV parking and maintenance location.

4 Energy and Economy

4.1 Research focus and methods

The energy and economy LOE focused primarily on the energy supply and demand and associated costs during the project, as well as some of the related infrastructure and operations impacts that are more fully covered in another chapter. This LOE used evidence from field observations, data collection, and fleet management report documentation. Units of analysis included the number of AVs, kilowatt-hours, miles driven, and hours of operation. The goal of this exploratory research was to characterize the energy and economic impacts of an AV transportation service on JBM-HH.

4.2 Data findings

4.2.1 Olli specifications related to energy

Range:	20-35 miles (with max load and nominal)
Max Passengers:	up to 8
Max Power:	160 kW (215 hp)
Continuous Power:	120kW
Max Speed:	25 mph (limited to 12 mph at JBM-HH)
Charge Time:	2 hours with Level 2 charging capabilities
HVAC* in Roof Unit:	8.5 kW Cooling; 10 kW Heating
Curb Weight:	6100 lbs.
Carrying Capacity:	2100 lbs.

*HVAC = Heating, Ventilating, and Air-Conditioning

4.2.2 Vehicle telemetry and energy use

Figure 29 shows a map of JBM-HH with data points that correlate with the position of the Olli 13 throughout the day on 10 July 2019, the AV's GPS points, and vehicle speed. The size of the bubble indicates the speed. Larger bubbles indicate higher speeds. The data were provided by Local Motors in the file titled "OlliNavFiles.tar.gz." While the speed range was from 13 mph maximum to 0 mph minimum, the maximum average speed that the Olli demonstrated was from 5 to 6 mph on the straightaways. The average speed throughout the entire route while the Olli was in motion was 4.23 mph.

Figure 29. Graphic showing Olli speed along shuttle route.

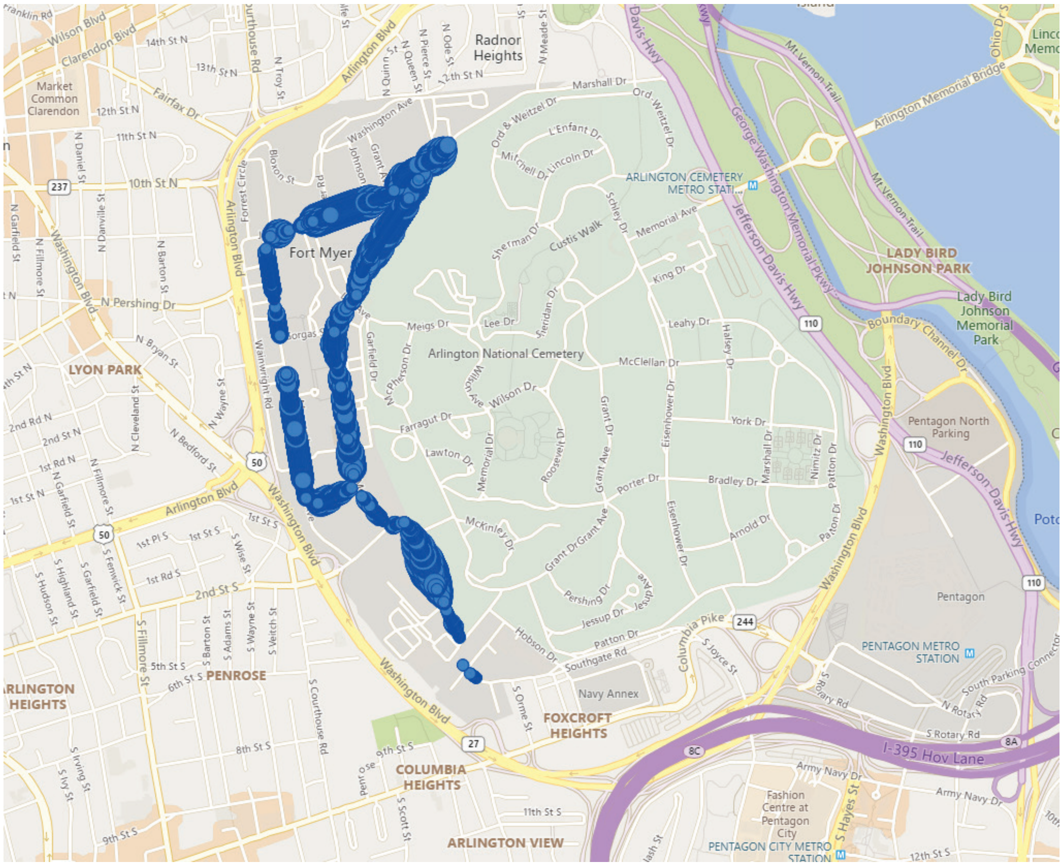


Table 3 lists a sample of the time stamp, location, speed, and acceleration data. The data shown represent a typical day and route (10 July 2019 for Olli 13).

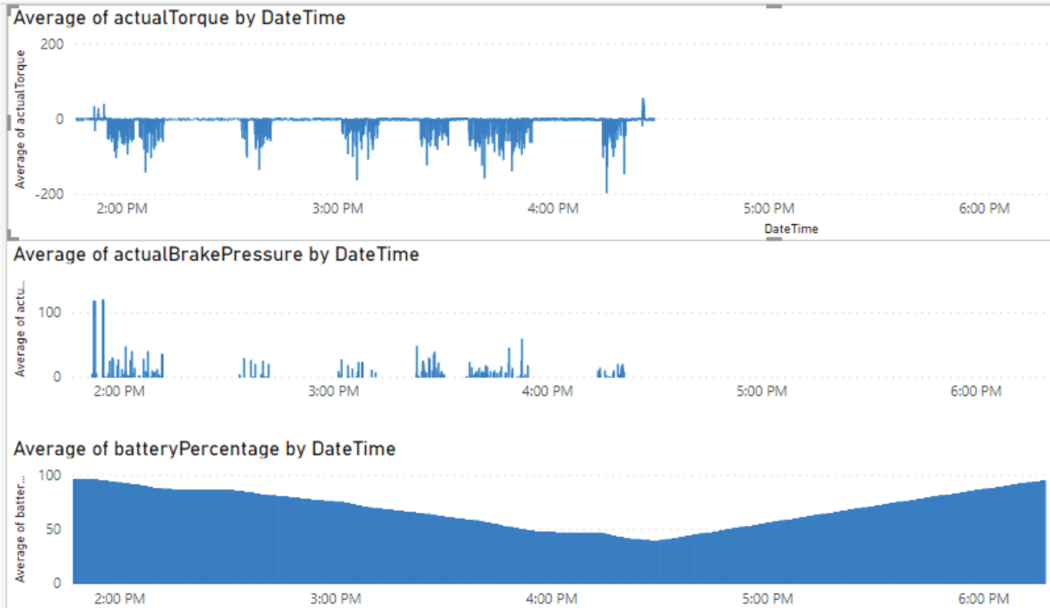
Table 3. Vehicle telemetry data from 10 July 2019 for Olli 13.

DateTime	bestLatitude	bestLongitude	Average of speed	accel
7/10/2019 3:44:25 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:40 PM	38.87	-77.07	2.00	1
7/10/2019 3:44:31 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:25 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:25 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:40 PM	38.87	-77.07	2.00	1
7/10/2019 3:44:31 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:14 PM	38.87	-77.07	2.00	0
7/10/2019 3:44:24 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:32 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:40 PM	38.87	-77.07	2.00	1
7/10/2019 3:44:24 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:14 PM	38.87	-77.07	2.00	0
7/10/2019 3:44:24 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:39 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:32 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:24 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:39 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:32 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:24 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:14 PM	38.87	-77.07	2.00	0
7/10/2019 3:43:39 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:23 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:32 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:39 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:23 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:39 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:23 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:14 PM	38.87	-77.07	2.00	0
7/10/2019 3:44:32 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:38 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:23 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:38 PM	38.87	-77.07	1.00	1
7/10/2019 3:44:23 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:33 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:14 PM	38.87	-77.07	2.00	0
7/10/2019 3:44:22 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:22 PM	38.87	-77.07	3.00	0
7/10/2019 3:43:25 PM	38.87	-77.07	1.00	-1
7/10/2019 3:43:25 PM	38.87	-77.07	1.00	-1
7/10/2019 3:44:33 PM	38.87	-77.07	4.00	0

DateTime	bestLatitude	bestLongitude	Average of speed	accel
7/10/2019 3:43:22 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:35 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:22 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:36 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:21 PM	38.87	-77.07	3.00	-1
7/10/2019 3:44:36 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:21 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:36 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:21 PM	38.87	-77.07	3.00	0
7/10/2019 3:44:36 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:21 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:21 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:36 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:20 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:37 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:20 PM	38.87	-77.07	4.00	-1
7/10/2019 3:44:37 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:20 PM	38.87	-77.07	4.00	-1
7/10/2019 3:44:37 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:20 PM	38.87	-77.07	4.00	-1
7/10/2019 3:44:37 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:20 PM	38.87	-77.07	4.00	-1
7/10/2019 3:44:37 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:19 PM	38.87	-77.07	4.00	-1
7/10/2019 3:44:38 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:19 PM	38.87	-77.07	5.00	-1
7/10/2019 3:44:38 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:19 PM	38.87	-77.07	5.00	-1
7/10/2019 3:44:38 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:19 PM	38.87	-77.07	5.00	-1
7/10/2019 3:44:38 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:18 PM	38.87	-77.07	5.00	-1
7/10/2019 3:44:38 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:18 PM	38.87	-77.07	5.00	-1
7/10/2019 3:44:39 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:18 PM	38.87	-77.07	5.00	0
7/10/2019 3:44:39 PM	38.87	-77.07	4.00	0
7/10/2019 3:44:39 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:18 PM	38.87	-77.07	5.00	0
7/10/2019 3:44:39 PM	38.87	-77.07	4.00	0
7/10/2019 3:43:18 PM	38.87	-77.07	5.00	0
7/10/2019 3:44:39 PM	38.87	-77.07	4.00	0
Total			**4.23**	

Figure 30 shows the torque, brake pressure and battery charge from 10 July 2019, which indicate how one of the vehicles was being operated. The battery's initial charge was 96% and ended at 39%. To get the battery back to full charge took just under 2 hours using the recommended single-phase charger, which was in line with the vehicle specification sheet.

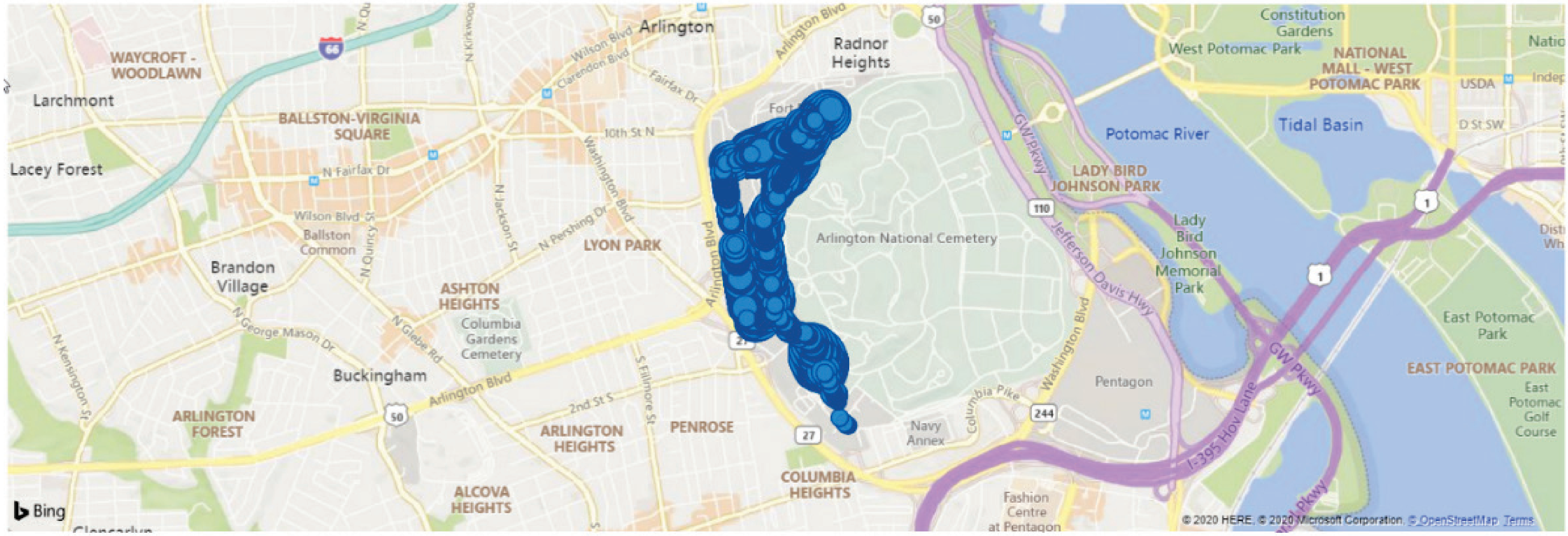
Figure 30. Vehicle telemetry data plotted for 1 day (10 July 2019).



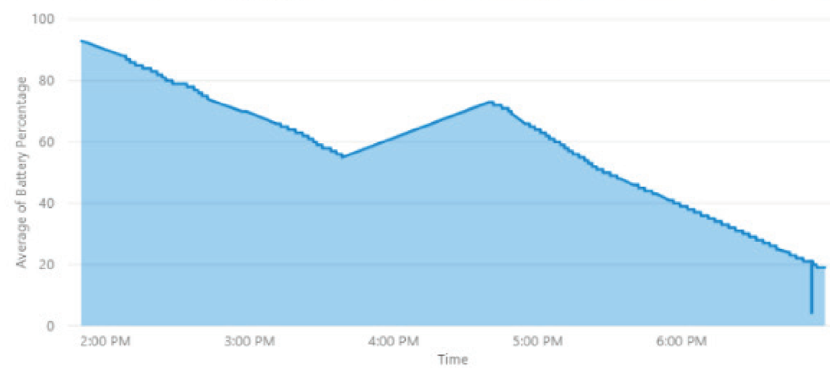
DateTime	batteryPercentage	actualTorque	actualBrakePressure	commandedBrakePressure	commandedTorque
7/10/2019 1:47:21 PM	96	-0.30	0	16.13	0
7/10/2019 1:47:22 PM	96	-0.70	0	16.13	0
7/10/2019 1:47:22 PM	96	-0.20	0	16.13	0
7/10/2019 1:47:22 PM	96	-0.70	0	16.13	0
7/10/2019 1:47:22 PM	96	0.10	0	16.13	0
7/10/2019 1:47:22 PM	96	0.10	0	16.13	0
7/10/2019 1:47:23 PM	96	-0.60	0	16.13	0

This dataset was analyzed based on a smaller 2-week sample of data provided by Local Motors that had GPS data location, time stamp, speed, and acceleration. These time and location data were not provided in the typical AV sensor data of the vehicle operation. These two datasets from 10 July were combined to create a document that associated time, battery percentage, latitude, longitude, speed, and acceleration with one another. The battery usage graph (Figure 31) shows what became a typical deployment day during the Phase 1b Route, where the AV would traverse the route in advance of the schedule to place sandwich boards for advertising at the various passenger loading/unloading locations, then go back to the garage to receive a full charge, then operate along the route during the 2-hour scheduled service period.

Figure 31. Detailed vehicle battery management system data plotted for 1 day (10 July 2019).



Time	Battery Percentage	Latitude	Longitude	Speed	Acceleration
1:49:46 PM	93	38.88	-77.08	0	0
1:49:46 PM	93	38.88	-77.08	0	0
1:49:46 PM	93	38.88	-77.08	0	0
1:49:46 PM	93	38.88	-77.08	0	0
1:49:46 PM	93	38.88	-77.08	0	0
1:49:47 PM	93	38.88	-77.08	0	0
1:49:47 PM	93	38.88	-77.08	0	0
1:49:47 PM	93	38.88	-77.08	0	0
1:49:47 PM	93	38.88	-77.08	0	0
1:49:48 PM	93	38.88	-77.08	0	0
1:49:48 PM	93	38.88	-77.08	0	0
1:49:48 PM	93	38.88	-77.08	0	0
1:49:48 PM	93	38.88	-77.08	0	0
1:49:49 PM	93	38.88	-77.08	0	0
1:49:49 PM	93	38.88	-77.08	0	0



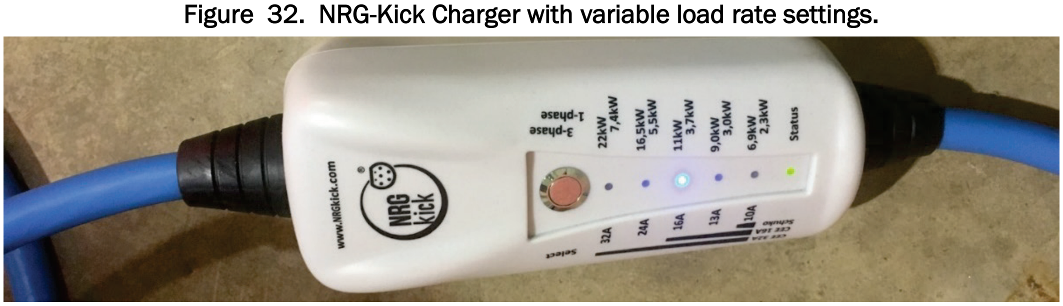
This produced values for battery discharge and the cost analysis for operating the Olli 13. From roughly 1:50 p.m. through 3:40 p.m., the Olli went from 93% charge to 56%, or 37% of its battery, thus giving an expenditure of 6.85kWh over a 1-hour, 50-minute timeframe. Given that the cost of electricity at JBM-HH is $0.07/kWh, it cost approximately $0.48 for operational energy to operate during this timeframe ($0.26/hr of operation). Although there is no direct data record displaying the distance traveled, location data show that two laps around the Phase Route 1b were traversed for a distance between 8.5 and 9 miles. Using an average of 8.75 miles, the cost per mile was $0.055/mile at an efficiency of 0.78kWh/mile.

Comparing this with the next set of discharge data from roughly 4:40 p.m. through 7 p.m., the Olli discharged 54% of its initial charge of 73%, giving it a charge of 19% whenever the dataset ended. This indicates that 10kWh were used during this trip and the cost was $0.70 for operational energy during this timeframe ($0.30/hr of operation). Assuming that the distance of the trip was the average 8.75 miles, this would give an efficiency of 1.14kWh/mile, which correlates to a cost of $0.70 for the entire trip or $0.08/mile.

Averaging the two trips produces an expenditure of 8.42kWh over an 8.75-mile distance. The efficiency would be 0.96kWh/mile, which calculates a cost of $0.07/mile. This suggests that the Olli could theoretically have a range of 16.88 miles on a full charge (19.23 miles in an emergency), which would cost $1.18 ($1.35 assuming 19.23 miles). This compares to the AV specification range of 20 miles for maximum load and 35 miles nominal per full charge.

This same sample data were used to analyze and evaluate the battery charging characteristics. The Olli 13's battery capacity went from 55% at 3:40 p.m. to 73% at 4:40 p.m. This is an increase of 18% or 3.33kWh over an hour timespan. Figure 32 shows the NRG-Kick charger used to supply electricity to the Olli's battery.

Figure 32. NRG-Kick Charger with variable load rate settings.



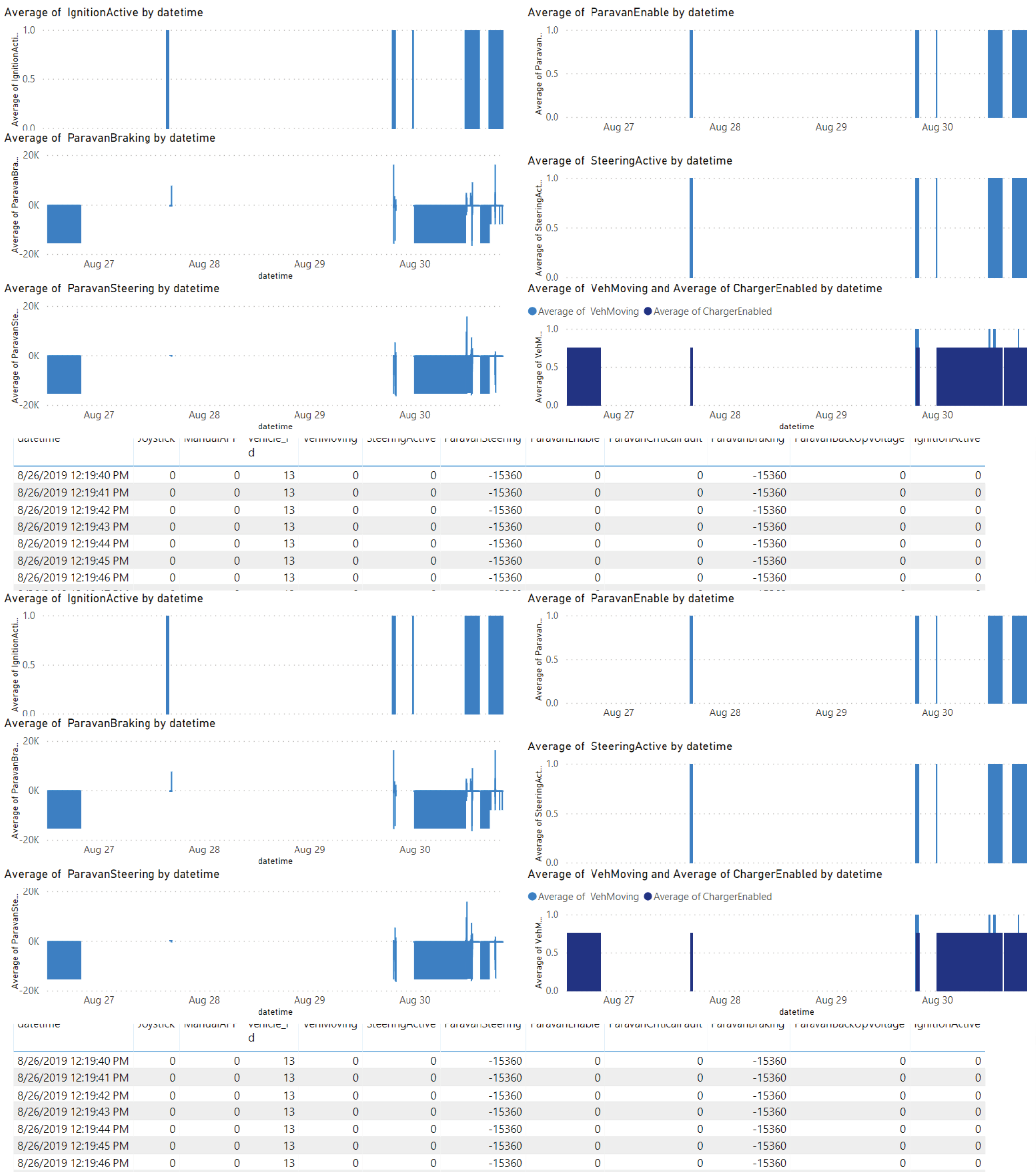
With the AV charging station set to supply 3.7kW as shown in Figure 32, the charger load was 3.7 kWh per hour. However, the data showed that the Olli only charged 3.33 kWh in the 1-hour timespan between rides. This suggests that there is an energy loss of 0.37 kWh or a 10% loss while charging. In a perfect scenario, it would cost $0.23 to supply the Olli 3.33 kWh of charge based on the Joint Base Myer-Henderson Hall electricity cost being $0.07/kWh. However due to losses, it took 3.7 kWh of electricity to charge the Olli's battery 3.33 kWh, which in turn lead to a cost of $0.26. Assuming a 10% loss is typical, this suggests that it would take 20.35 kWh of electricity to charge the battery from completely dead to the full 18.5 kWh capacity, at a cost of $1.43 (instead of $1.30).

Local Motors also provided raw data from each Olli for the weeks of August 26 through the 30, as well as July 9 through the 13. These datasets provided insight into when the AV was operating autonomously as opposed to being operated by the attendant, as well as the current and voltage being supplied to the Olli's battery while charging, and the torque and temperature readouts from the electric motor. Correlating these data with location, time, other vehicle control unit and sensor data to provide meaningful analytics was problematic as the datasets were disparate, had unexplained anomalies, such that further analysis was beyond the scope of this exploratory research project. However, a display of the data format (Figure 33) can inform future military installation use-case and data analytics development.

4.2.3 Fleet operations and energy use

Data reporting was also received and analyzed from the fleet management operators with daily reports and weekly roll ups of information collected and recorded by the AV safety stewards and fleet manager.

Figure 33. Examples of other vehicle control unit data captured along with energy data.



These reports included useful information regarding the AV's respective start and finish times for the route embarked with key factors such as miles driven, number of passengers per ride, and beginning and ending battery charge percentage. Appendix G includes the complete reports. Using these report summaries from 26 through the 30 August, an assessment of the overall average kWh per mile was determined, giving a value of 0.69 kWh/mile. This rate of energy use is slightly less than the low end of the range calculated from the actual vehicle system sample data (range of 0.78 to 1.14 kWh/mile) and is directly associated with the actual runtimes of the AV, and with runtimes reported by the attendant operating the vehicle, including much variability due to such factors as load carried or running of air-conditioning while not traveling. Thus, the measure provides some validation that operational energy use likely falls in a broader range for ongoing operations.

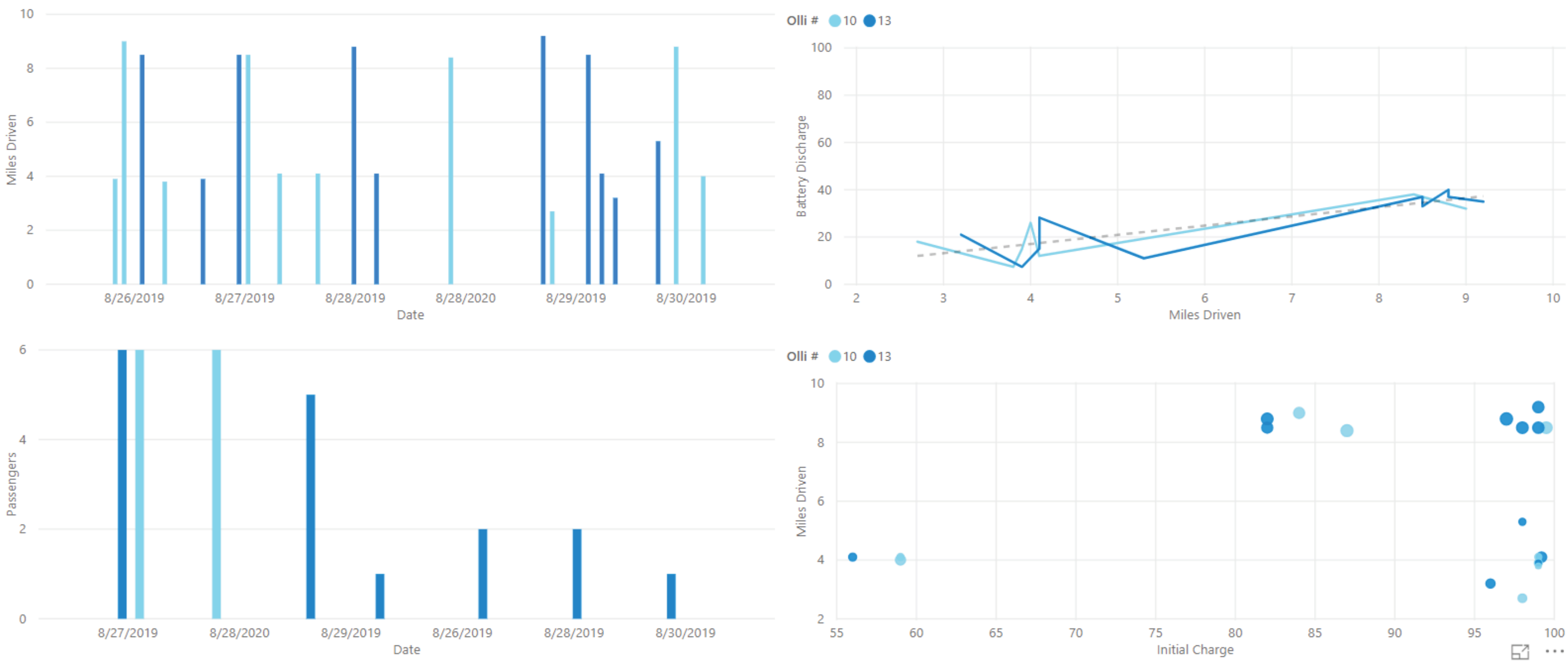
Figure 34 shows a visual summary of the data extracted from the fleet managers report. The data were imported into Power BI* as a way to compare and contrast the various aspects of each of the trips the AVs made from 26 through 30 August. The light blue line indicates the Olli 10 while the dark blue line is Olli 13. Figure 34 shows the distances driven by each AV throughout the week, trend lines that compare and contrast the miles driven per trip with the battery discharge, a passengers per date plot, as well as a miles driven vs. initial charge graph where the data points are sized according to the amount of battery charge lost.

The data demonstrate that both AVs experienced a significant increase in the energy demand around the 4-mile mark before sharply decreasing. Detailed analysis of this specific issue was not feasible due to the inability to directly correlate location of the AV with granular data on passengers and loading at a given time, or the use of the HVAC system. It is thus difficult to suggest what caused a substantial jump in the energy demand although the relatively steep 7% grade in a portion of the route is a likely factor. On the day of the substantial jump, the Olli 10 was being used to pick up signs, so no excess passengers were on board. The weather conditions record states that it was 79 °F and sunny; it is thus assumed that the air-conditioning could have contributed to loading. Almost similar conditions were noted in the substantial jump of the Olli 13 where the vehicle was being used to pick up signs and the weather conditions recorded were 80oF and sunny.

The bottom right graph along with previous battery drain analysis indicate that battery power capability and rate of discharge is consistent regardless of percent of battery life remaining. A comparison of the routes at varying initial battery charges reveals that there were no significant differences between the energy demands of a battery at full charge and a battery not fully charged. This suggests that the AVs battery percentage indicator is consistent with its change in percentage in correlation with the exhaustion of kWh across multiple initial charge levels.

* Business Intelligence (BI)

Figure 34. Energy demand and use comparison of Olli #10 and Olli #13 sample data.



Olli #	Date	Start Time	Finish Time	Passengers	Miles Driven	Initial Charge	Battery Discharge	Ending Charge	kWh/mi	$/Trip
13	8/27/2019	10:50:00 AM	1:00:00 PM	6	8.50	98.00	37.00	61.00	0.71	0.41
10	8/27/2019	11:13:00 AM	12:48:00 PM	6	8.50	99.50	36.96	62.54	0.70	0.41
10	8/28/2020	10:41:00 AM	12:33:00 PM	6	8.40	87.00	38.00	49.00	0.73	0.41
13	8/29/2019	9:01:00 AM	10:45:00 AM	5	9.20	99.00	35.00	64.00	0.62	0.44
13	8/26/2019	11:15:00 AM	1:15:00 PM	2	8.50	99.00	35.00	64.00	0.76	0.41
13	8/28/2019	11:00:00 AM	1:15:00 PM	2	8.80	97.00	40.00	57.00	0.74	0.42
13	8/29/2019	11:20:00 AM	12:51:00 PM	1	8.50	82.00	33.00	49.00	0.63	0.41
13	8/30/2019	10:49:00 AM	12:52:00 PM	1	8.80	82.00	37.00	45.00	0.68	0.42
10	8/27/2019	2:26:00 PM	2:56:00 PM	0	4.10	59.00	12.00	47.00	0.47	0.20

An analysis of the cost of energy using the fleet management reports data, again based on the price of a kWh at JBM-HH of $0.07/kWh, gives an average cost of $0.05/mile (previous range $0.055 to 0.08/mile). The Olli has a maximum battery capacity of 18.5 kWh, but the fleet manager protocol was to ensure that the battery charge stayed above 20%, thus if the vehicle did drop to 25%, the safety steward would immediately drive the vehicle back to the charging station location to ensure the vehicle did not lose power in a manner or place that was unsafe. The comparison of the fleet management data to the actual vehicle sensor and vehicle control unit data provided a more robust analysis of the energy use and costs during the project.

4.3 Operations cost comparison

A direct comparison of operation was conducted as a way to evaluate the cost-estimated difference between the 200hp diesel bus (Myer Flyer) currently in place and the Olli autonomous-electric vehicle to determine if the Olli would be a viable alternative for transporting individuals to and from JBM-HH and the Pentagon. Costs for mileage, lease, and a driver's hourly wage to operate each vehicle were determined, and a comparative analysis was completed assuming maximum use of both vehicles as the extreme case. In this comparison, it is assumed that the route will be operational Monday through Friday, for 7 hours per day, resulting in an estimated 14,560 miles driven annually (based on information received from JBM-HH).

The cost to operate the Myer Flyer is $0.329 per mile. Over the course of a day (56 miles), this amounts to roughly $18.42 in operational costs, or $4,790.24 annually. The average passenger car operates at $0.076 per mile. Thus, the Myer Flyer costs roughly 4.3 times more in operational cost per mile than typical personal transportation. The average cost per passenger on the Myer Flyer is $0.275 for a 2-mile trip. Individuals would spend roughly $0.15 in operational costs to travel the same 2-mile route that the Myer Flyer services, but in their own personal vehicles. Increasing the number of passengers in either case reduces the operational cost per passenger proportionally. However, the Myer Flyer acts as a free service to riders meaning that individuals wanting to use the shuttle's service would not be prompted to pay any operational cost, while those taking personal transportation would. The data outlined in Table 4 provide the basis for cost comparisons.

Table 4. Comparisons between Myer Flyer and Olli.

	Current Mode	Proposed Mode
		
Vehicle	**Standard Bus (Myer Flyer)**	**Electric - Automated Vehicle (Olli)**
Power source	200hp Diesel Engine	135hp Max / 40hp Continuous Electric Motor (100kW Max / 30kW Continous)
Passenger Capacity	20 person	8 person
Management	GSA Fleet	Local Motors
Operation	M-F, 7 hours per day	M-F, 7 hours per day
Route	14,560 miles annually	14,560 miles annually

	Costs	Annual Cost	Cost	Annual Cost
Mileage Cost	$0.329 per mile	$4,790.24	$0.05 to $0.08 per mile ($0.065 Average)	$1,041.04
Cost Per Passenger	$0.275 per trip	-	$0.06 per trip	-
Lease	$28.83 per month	$345.96	$1000 per day	$365,000.00
Driver Cost	Driver, $27.51/hr, 8 hours per day	$57,220.80	Safety Steward, $30/hr, 8 hours per day (Included in Lease)	$62,400.00
	Total:	**$62,357.00**	**Total:**	**$428,441.04**

The Olli has a significantly less operational cost than does the Myer Flyer shuttle. The Olli has an average operational cost of $0.065 per mile with an assumed 10% loss of electricity during charging. Thus, the Olli would cost $4.00 per day or $1,041.04 annually. This represents a savings of $3,749.20 compared to the Myer Flyer. The Olli cost is $0.060 per passenger for each 2-mile trip. This is 8 times less than the Myer Flyer and slightly less than a typical passenger car. However, like the Myer Flyer, the Olli would be a free service to the passengers. These estimates only reflect the cost to operate the vehicle, and do not include maintenance, ownership/lease, or driver/safety steward.

The diesel bus or the Olli would be leased from the General Services Administration (GSA) Fleet or from Local Motors, respectively. This represents a large difference in cost given that the lease of the diesel bus would be a mere $28.83 per month while the Olli is priced at $30,000 per month (based on $1,000 per day). However, the Olli's lease includes the salary of the safety steward that maintains control of the vehicle in the event that human intervention is necessary. The salary of the Myer Flyer's operator is not included in its lease. Annually, the Olli lease is $365,000.00, including the safety steward's salary, while the diesel bus is $345.96, not including the driver's salary.

The salary of the operators for the diesel bus and the Olli are more comparable. The hourly wage for the current diesel bus driver is $27.51 per hour for 8 hours a day. This gives the driver a salary of roughly $57,220.80. The Olli's operator would get a similar wage of $30 per hour for 8 hours a day, for an annual salary of $62,400; however, as mentioned, this salary is included within the lease of the Olli. Due to the Olli's autonomy, the safety steward could theoretically be phased out over time. This would reduce the overall annual cost by a factor of the steward's salary, which would be a significant portion of the Olli's price.

The Olli does partially compensate for a higher lease price by its operational efficiency over the diesel shuttle bus. The test data collected at JBM-HH indicate that the Olli cost between $0.05 to $0.08 per mile. Over the roughly 14,560 miles expected to be driven by the shuttle annually, this would produce a minimum, maximum, and average annual cost of $728.00, $1,164.80, and $946.40, respectively. The diesel bus costs approximately $0.329 per mile according to the fleet manager's calculations, which yields an annual cost of $4,790.24. Annually, the Myer Flyer costs approximately $3,749.20 more to operate than the Olli.

A 2017 Ohio State University study referencing the same make and model of the Olli and doing a similar analysis resulted in findings similar to those of this JBM-HH project. The Ohio State study compared the use of an Olli to transport university materials across campus and to act as a secondary mode of transportation for students against the use of the university's fleet vehicles and shuttles. Ohio State University concluded that even purchasing an Olli from Local Motors outright was not a viable solution as the price of the technology still supersedes that of using a fleet vehicle or a shuttle to do the same task currently. The Olli outperformed in operational and maintenance costs of both the fleet vehicle and shuttle in the university's study, and also produced less carbon emissions overall. In the end, the initial $275,000.00 price tag of the Olli greatly outweighed that of the fleet vehicle and shuttle combined, regardless of any additional cost saved on fuel and maintenance.

Ultimately, the total cost comparison between the diesel bus and the Olli are incomparable. It is roughly 6.9 times more financially efficient to operate the diesel bus as compared to the Olli, with the diesel bus having a yearly operational cost of roughly $62,357.00, while the Olli's would be $428,128.00. A vast majority of the diesel bus's yearly cost is allotted to the

(~$57,220.80) operator's salary. This leaves a price of $6,703.96 to both lease and operate the bus on the determined route for the entire year. The relatively higher cost of the Olli is primarily due to the annual lease from Local Motors. Regardless of options to lease or purchase an Olli outright, the annual cost difference would still greatly outweigh that of the diesel bus. (Note that the documentation of ongoing maintenance and repair costs for extensive use of the Olli was beyond the scope of this project.)

4.4 Transport cost comparison

When comparing alternatives, the main considerations of public transportation options are capacity, serviceability, and efficiency. This section takes a transit services viewpoint to analyze and compare passenger travel options. The analysis is based on observations of the #9 shuttle route that provides passenger service from JBM-HH to the Pentagon's Transit Center using data and estimates for maximum capacity, person-miles traveled, as well as the person-hours traveled annually. The comparison contrasts the Myer Flyer shuttle on the same route with either the Olli autonomous-electric vehicle or a personal passenger vehicle. The following costs have been assumed: national average gas mileage of 24.2 miles per gallon; national average cost of $1.841 per gallon of gas.

4.4.1 Myer flyer analysis

The Myer Flyer is one of two public transit systems between JBM-HH and the Pentagon, which services an average of 67 individuals per day with a maximum capacity of 20 passengers at a given time. The Myer Flyer services the route for a total of 7 hours a day during peak transit times in the morning and afternoon, 5 days a week, every week of the year. The route is roughly 4 miles in length, round trip, taking roughly half an hour including multiple stops along the way. Thus, the total vehicle miles of travel (VMT) per day is 56 VMT or 14,560 VMT annually. This analysis assumes that the average passenger travels 2 miles during his or her ride. Thus, the total person-miles of travel (PMT) is 134 PMT per day, or 34,840 PMT annually. The ratio of PMT to VMT for the Myer Flyer is 2.4.

Comparatively, a person driving their own car for any distance, the ratio of PMT to VMT is 1. For each additional passenger, the ratio doubles. Thus, the Myer Flyer represents the equivalent of a 2-3-person carpool. We note that it is unlikely that the Myer Flyer has approximately 2.4 passengers onboard at all times. Rather, it is likely that during periods of peak travel, there are higher numbers of passengers, and zero at other times. The maximum ratio of PMT to VMT attainable by the Myer Flyer could be 20.0 when all seats are filled, which is 4 times greater than an average passenger car's maximum ratio of 5.0.

For each Myer Flyer passenger onboard for 2 miles, he or she spends roughly 15 minutes traveling on the shuttle, thus accounting for 16.75 person-hours traveled (PHT) per day (based on the average daily passenger count of 67). Annually, the Myer Flyer averages 4,355 PHT, compared with 1,820 vehicle hours traveled (VHT). The ratio of PHT to VHT is also 2.4.

4.4.2 Olli analysis

The Olli shuttle would theoretically yield the same results as the Myer Flyer for the vehicle and person-miles traveled analysis along the JBM-HH #9 shuttle route. Using similar ridership as the Myer Flyer, the Olli would achieve a PMT to VMT ratio of 2.4 (same as the current shuttle). Coincidentally, this is comparable to a 2-3-person carpool. The maximum ratio of PMT to VMT is 8, which would be achieved when the Olli is operating at maximum capacity. This ratio is less than half of the Myer Flyer's maximum ratio of 20, though still greater than a typical personal vehicle's ratio of 5. Due to the Olli's reduced capacity compared to the Myer Flyer, total volume of passengers transported along the route may suffer during peak transit times when demand is higher than what the Olli can support.

Assuming similar operation parameters as the Myer Flyer, passengers would spend roughly 15 minutes in transit along the 2-mile distance from the Pentagon Transit Center to JBM-HH, accounting for 16.75 PHT per day for 67 passengers a day average. An average of 4,355 PHT and roughly 1,820 VHT would likely be observed creating a ratio of PHT to VHT of 2.4.

4.4.3 Service demand and timeliness comparison

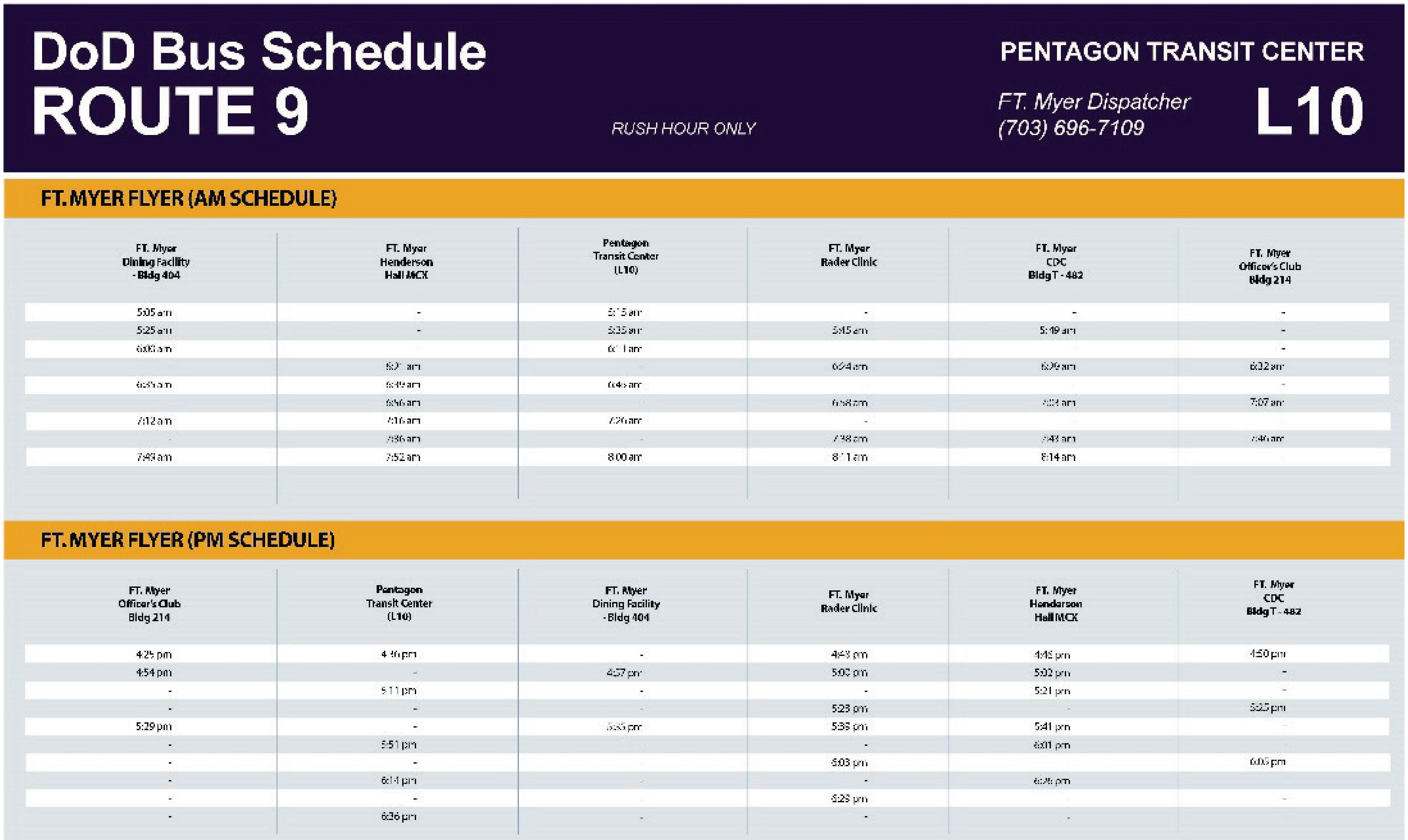
The Myer Flyer services portions of JBM-HH to connect the base to the Pentagon's Transportation Center. Operating along the #9 shuttle route (schedule shown in Figure 35), the Myer Flyer arrives at its first stop of the morning at the dining hall at 5:05 a.m. From the dining hall, the shuttle makes periodic stops at the Marine Corps Exchange, the Pentagon's Transportation Center, the Rader Clinic, the Officer's Club, and the Child Development Center until 8:14 a.m. Public transportation to and from JBM-HH and the Pentagon is then halted until the afternoon when the shuttle continues its service along the route by arriving at the Officer's Club at 4:25 p.m. Periodic stops are then made to all destinations previously stated until 6:36 p.m.

Although the Myer Flyer's serves key locations throughout JBM-HH and establishes a connection to the Pentagon, the consistency of the service is limited due to it only being offered during peak transit times in the mornings and afternoons. This creates a roughly 8-hour gap for public transportation from 8:15 a.m. to 4:25 p.m. for those who use the shuttle's service, leaving them to find alternative means of travel – some having to walk as a result. Assuming an individual had to walk the 2 miles from where they originally boarded the Myer Flyer, the person-hours accumulated per individual would be 0.67 assuming an average 3 mph walking speed. If an individual were to have to walk this distance every day due to the lack of public transportation service midday, this would amount to 173.33 person-hours per each individual annually.

This lack of public transportation serviceability midday incentivizes the use of personal vehicles for those who need to travel during the midday yet do not have the time or desire to walk to their destinations. Expanding the Myer Flyer's schedule to include a midday route could potentially increase the ridership by offering incentives for both those who find themselves walking to their destinations, and for those who are using their own personal transportation by offering them a convenient alternative. Those individuals who walk along the #9 route to their destinations would save roughly 0.417 person-hours per day if the service were to operate during this timeframe. As for those who currently use personal transportation, the shuttle service could potentially be an alternative with less environmental impacts and a reduction in personal operational costs for transportation.

Additional funding would be needed to operate a shuttle during the midday time frame at JBM-HH. The fleet manager noted that any GSA fleet vehicle, such as the Myer Flyer, was an asset that could be used for other transportation service requirements. This flexibility of use was valued by the fleet manager over alternatives like the Olli, which was limited to a designated route and could not attain higher speeds for public highway use. However, an AV did present an alternative in which the limited use of the Olli could complement transportation service at JBM-HH during the midday timeframe if the Myer Flyer were on another mission trip.

Figure 35. DoD Bus Route #9 Schedule.


DoD Bus Schedule
ROUTE 9

RUSH HOUR ONLY

PENTAGON TRANSIT CENTER
FT. Myer Dispatcher
(703) 696-7109
L10

FT. MYER FLYER (AM SCHEDULE)

FT. Myer Dining Facility - Bldg 404	FT. Myer Henderson Hall MCX	Pentagon Transit Center (L10)	FT. Myer Rader Clinic	FT. Myer CDC Bldg T - 482	FT. Myer Officer's Club Bldg 214
5:05 am	-	5:15 am	-	-	-
5:25 am	-	5:35 am	5:45 am	5:49 am	-
6:00 am	-	6:[illegible] am	-	-	-
-	6:2[illegible] am	-	6:24 am	6:29 am	6:32 am
6:35 am	6:49 am	6:45 am	-	-	-
-	6:56 am	-	6:58 am	7:03 am	7:07 am
7:12 am	7:16 am	7:20 am	-	-	-
-	7:36 am	-	7:38 am	7:43 am	7:46 am
7:43 am	7:52 am	8:00 am	8:11 am	8:14 am	-

FT. MYER FLYER (PM SCHEDULE)

FT. Myer Officer's Club Bldg 214	Pentagon Transit Center (L10)	FT. Myer Dining Facility - Bldg 404	FT. Myer Rader Clinic	FT. Myer Henderson Hall MCX	FT. Myer CDC Bldg T - 482
4:25 pm	4:36 pm	-	4:43 pm	4:48 pm	4:50 pm
4:54 pm	-	4:57 pm	5:00 pm	5:02 pm	-
-	5:11 pm	-	-	5:21 pm	-
-	-	-	5:23 pm	-	5:25 pm
5:29 pm	-	5:35 pm	5:38 pm	5:41 pm	-
-	5:51 pm	-	-	6:01 pm	-
-	-	-	6:03 pm	-	6:05 pm
-	6:14 pm	-	-	6:26 pm	-
-	-	-	6:28 pm	-	-
-	6:36 pm	-	-	-	-

Timeliness would also vary with speed of the vehicle. A previous comparison assumed equivalent speeds between the Olli and Myer Flyer, but in the case of this pilot, the Olli was programmed to operate at no more than 12 mph. Assuming the Myer Flyer operated at 25 mph (the posted speed limit), then in theory, the Olli will take twice as long to reach its destination, will reach 50% fewer stops, and transport 50% fewer passengers over the same time period. The lower speed will have an effect on the total vehicle miles traveled as well as the total person-miles traveled, and thus impact the value and utility of the service.

4.5 Results and recommendations

The following recommendations and key results are based on the energy and economy LOE. It is important to recognize that these are based on a single case study deployment of a single AV type on one military installation during the predominantly warmer summer months in eastern Virginia, USA. However, many of the findings were generalizable into the following key considerations.

- Battery drainage of the AV was higher than expected during operations and is a constraint. While the average range for the AV specifications was 20 miles for maximum load and 35 miles nominal, the realized range was on the order of 16 to 19 miles, or approximately 55% of nominal. A single fast AV charging station was installed on the military installation and used alternatively to charge the two AVs.
- The Olli has a maximum battery capacity of 18.5 kWh, but the fleet manager’s protocol was to ensure that charge stayed above 20% of battery, thus if the vehicle did drop to 25%, the safety steward would immediately drive the vehicle back to the charging station location to ensure the vehicle did not lose power in a manner or place that was unsafe. This business practice should be considered in route selection, charger location, and overall planning.
- Cost of operational energy for the AV ranged from \$0.05 to \$0.08/mile driven; and \$0.26 to \$0.30/hr of operation during fixed route transportation service based on the current price at JBM-HH of \$0.07/kWh. Efficiency of AV operation ranged from 0.69 kWh/mile to 1.14 kWh/mile. Energy usage and consumption for AVs varies with context of operations to include topography, temperature, vehicle and cargo weight, acceleration/deceleration zones, and additional battery loads such as heating/air-conditioning, and frequency of opening and closing of doors.

- The data revealed a 10% loss in energy between the charging station power required and the battery charge received. This is a reasonable planning factor for converting operational energy demand to supplied energy and cost.
- Developing language for competitively bid AV mobility service should consider energy requirements and performance and whether government or contractor is responsible for each.
- The datasets from the AV are disparate and difficult to integrate for evaluation of energy use, miles driven, hours of operation, vehicle status, and location in a time sequence that allows detailed econometric analysis. Future data indexing and collection should consider this in the data architecture design stage for determining data collection frequency, latency, and integration goals of the project.
- Understanding the full range of data collected by the vehicle control unit and battery management system is useful in developing use-cases for AV sensor data and second-order benefits of AV deployments such as condition assessments, facility monitoring, or emergency operations notifications.

5 Data Architecture and Cybersecurity

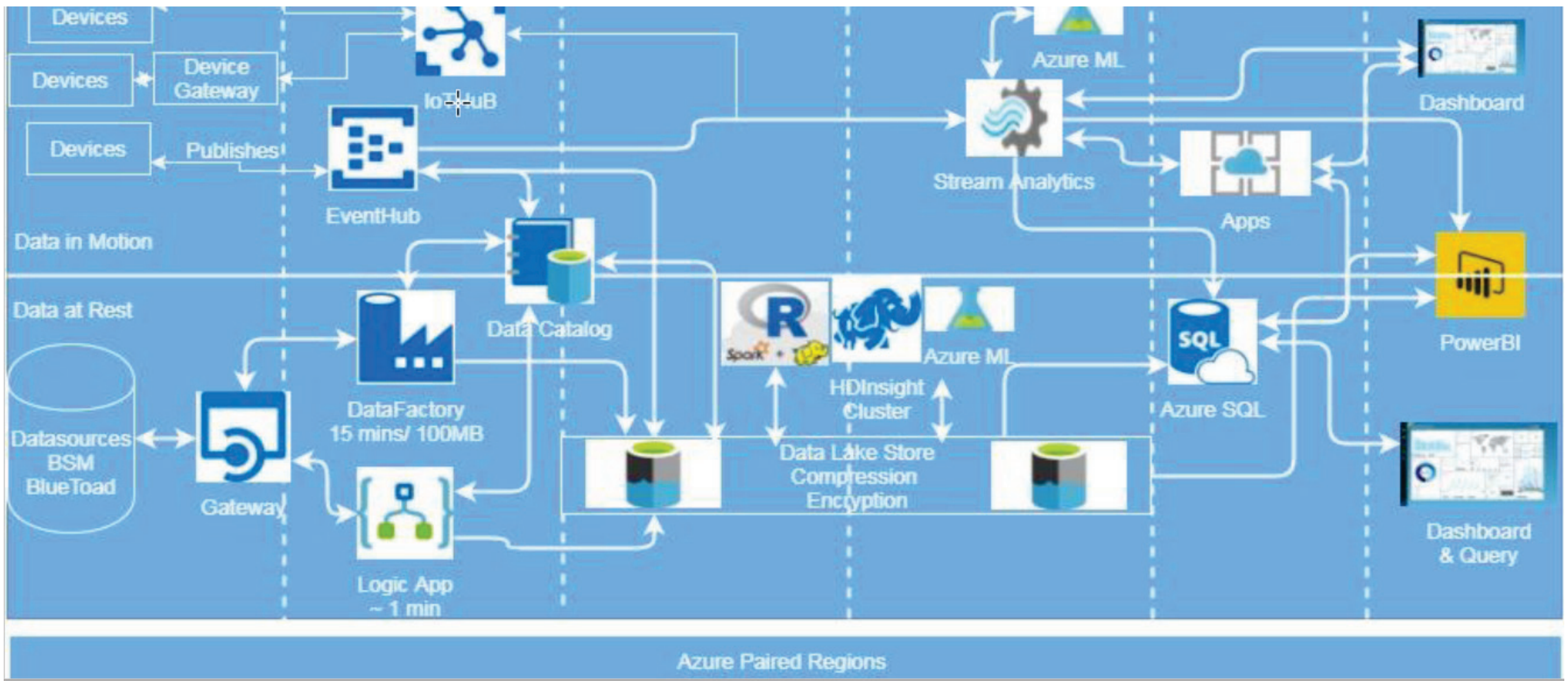
5.1 Research focus and methods

The data architecture and cybersecurity LOE focused primarily on the capture, storage, and transmission of data during the project, and the associated risk of security compromise of the data in this process. This LOE used evidence from field observations, data collection, and data management documentation. Units of analysis included the number of terabytes, time, and hours of effort. The goal of this exploratory research was to characterize the data and cybersecurity impacts of an AV transportation service on JBM-HH.

Data architecture and design form the backbone of the digital infrastructure required to operate, optimize, and integrate AV technology into the enterprise data system. A best solution depends on the specific installation and their capabilities, mission priorities, and future plans. Smart installation concepts are learning from the extensive experience of smart cities over the past several years. As an example, Figure 36 shows a highly designed enterprise data management architecture example that progresses from data sources, to data ingestion, to data preparation, to data analysis, to results publication, through results consumption. Each of these steps requires understanding and forethought in design and where and how an AV technology system fits.

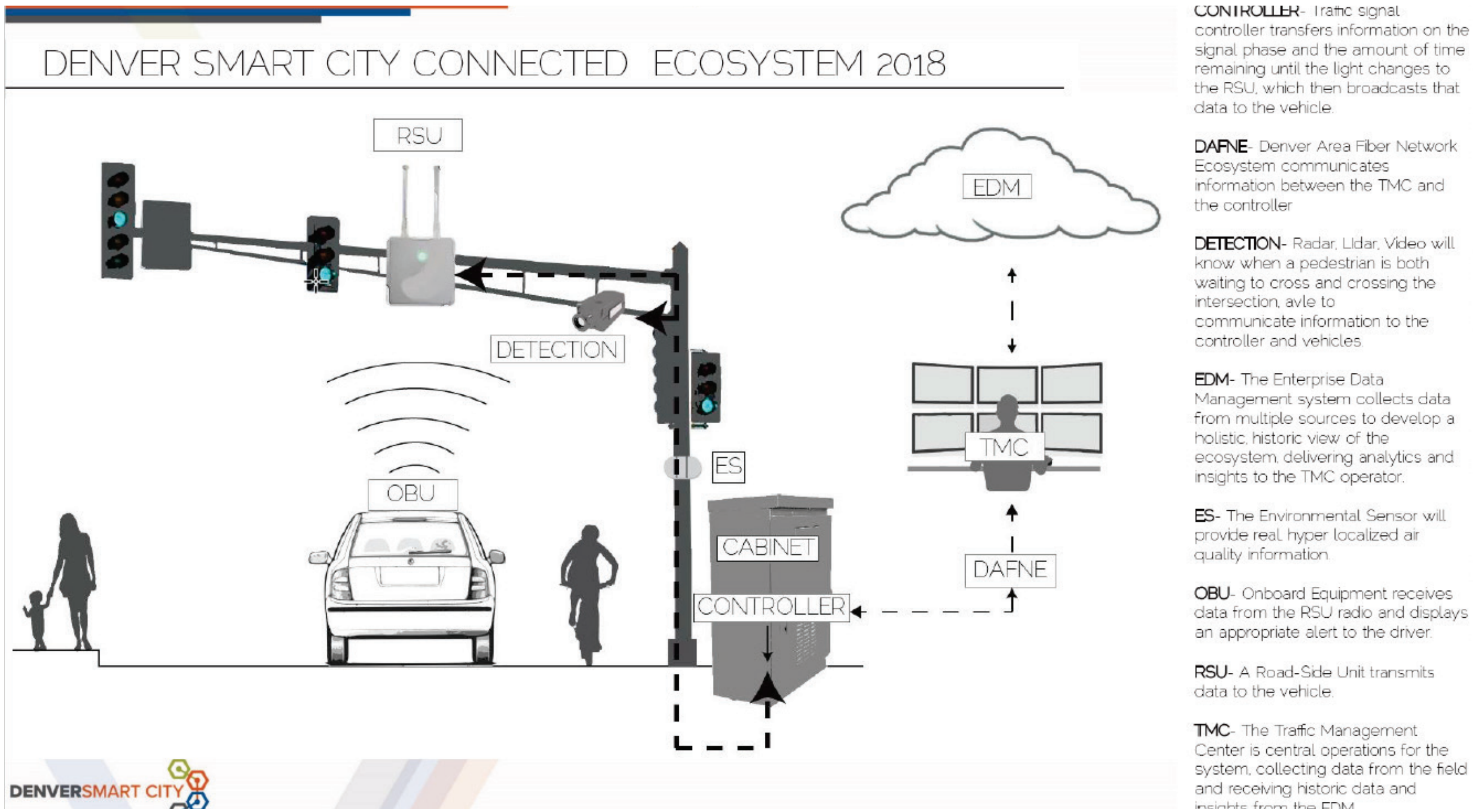
To capture, store, and transmit data into the enterprise data architecture an AV and other related and connected infrastructure requires digital equipment. While a detailed explanation of these technologies exceeds the scope of this report, Figure 37 shows one example from the city of Denver, which serves as a leader in smart transportation technologies. This level of advanced technology and data architecture design were not present during the JBM-HH project but are highlighted here to give context for future requirements for fully integrated and optimized AV deployments on installations.

Figure 36. Example enterprise data management architecture from Denver Smart Cities.



Source: Denver Smart Cities Connect Forum, James Lindauer, IOT Lead Architect, April 2019

Figure 37. Example AV to enterprise data equipment and infrastructure requirements.



Source: Denver Smart Cities Connect Forum, James Lindauer, IOT Lead Architect, April 2019

Olli vehicle implementation at JBM-HH was a joint venture between two companies, Robotic Research and Local Motors. Robotic Research provided the hardware and software for route planning and obstacle avoidance, while Local Motors provided the vehicle (motor, chassis, body, etc.). There were two datasets, the first collected by Robotic Research's six LiDAR sensors, five radar sensors, and six video camera feeds. The second was telemetry collected from the vehicle, such as battery charge, torque, sensor faults, etc. and was provided by Local Motors. This chapter focuses on the review and architecture of these datasets.

5.2 Data and findings

5.2.1 Data organization and architecture issues

It was difficult to marry the time sequences between all of the devices into a picture of what was happening on the vehicle for a given window. This was because the two vendor datasets had different mechanisms for indexing and querying their respective data.

Robotic Research did have a smart naming convention for the files (camera imagery, LiDAR, radar) that described the time the data were captured. The smart naming convention devised by the company was essential for indexing the information and understanding how datasets lined up temporally, especially considering how many data files were present (See Appendix I). However, another issue that obstructed analysis of the data was the raw format, PCAN (see Appendix I), which required post-processing using scripts. The post-processing was accomplished either by hand or by developing tools to do conversions of the datasets into something more user friendly (mp4 video, LiDAR visualization, etc.).

The second dataset from Local Motors was accessed through an application program interface (API). The data collected from the Local Motors onboard sensors were captured at 1-second intervals, resulting in a large dataset. There was not a smart naming convention for this dataset, which made it difficult to combine with the Robotic Research data in an automated fashion.

The Local Motors API has a number of parameters that allow for specific querying, such as the date of collection and vehicle identification number for the specific information being requested at the URL endpoint (see Appendix J). However, the data that were returned were limited as was the

API, and there was no mechanism for querying data at a specific time of day. This makes it difficult to find a specific window of activity where Robotic Research and Local Motor datasets can be combined. Still, the issue of greatest concern was that the Local Motors API could not handle multiple calls concurrently, therefore the throughput of the data collection process was extremely limited. It would take tens of thousands of API calls to extract a large dataset. To alleviate this issue, Local Motors provided a large data dump containing information available from the API. However, it is recommended that vendors provide automated mechanisms of data querying for larger amounts of information in a robust manner.

Appendices C and D contain examples of the Robotics Research and Local Motors Datasets, respectively.

5.2.2 Cybersecurity

Because this version of the Olli is not network connected, most of the data security revolves around the physical security of the hard drive on the vehicle that houses the data. When the data are offloaded manually and stored on servers at Robotic Research and Azure Government Storage accounts, the data are transferred over SSL (secure socket layer) using built in keys provided by Azure for encryption. Currently, there have been 92,092 files uploaded to the Government Azure Blob Storage Account for a total of about 5.5 terabytes dating from July 2019 to September 2019.

The second dataset (vehicle telemetry provided by Local Motors) can only be accessed through an SSL enabled Rest API that employs user name authentication and token authorization (both provided by Local Motors).

5.3 Results and recommendations

The following recommendations and key results are based on the data architecture and cybersecurity LOE. It is important to recognize that these are based on a single case study deployment of a single AV type on one military installation. However, many of the findings were generalizable into these key considerations.

- A standardized mechanism for indexing data from various sources of AV technology systems is needed to establish a solid data architecture and allow common data queries and effective application of post-processing methods and data analysis.

- Data security for the project was high; however, this was primarily due to the self-containment of the AV system on the vehicle with no reliance on any external network access. Although this was secure, it also resulted in a lack of real-time data transfer. Data transfer into secure government cloud storage occurred manually through periodic offloading via portable hard drives and overnight uploading with secure offsite internet connections. Edge computing and real-time data were limited in this configuration. This highlights the trade-off between risk and value.
- Reliability of the AV was uncertain based on instances of hard reboot requirements for the onboard system, which resulted in AV inoperability. Apparent fragility of the technology stack and integration with the AV sensor package demonstrated a need for continued development of more robust and resilient data processing and technology systems.
- Sharing data requires a specific, complex intergovernmental agreement or memorandum of understanding that entails extensive legal review. Data sensitivity, privacy, ownership, stewardship, reporting, restrictions, and disclosure are all important considerations.
- The AV fleet manager or a key person on the AV delivery team needs to have CAC-access to the DoD network if they will interact with a DoD-approved system. This was not required during this pilot but was noted as important for future considerations and data sharing.
- Developing and documenting physical, operational, communications, and cybersecurity assessment protocols will require further research studies and use-case applications with multiple AV technologies at varied installation locations with diverse missions. Both the data environment and the applications require an integrated security approach that is currently ill-defined in the 4G and 5G networks.

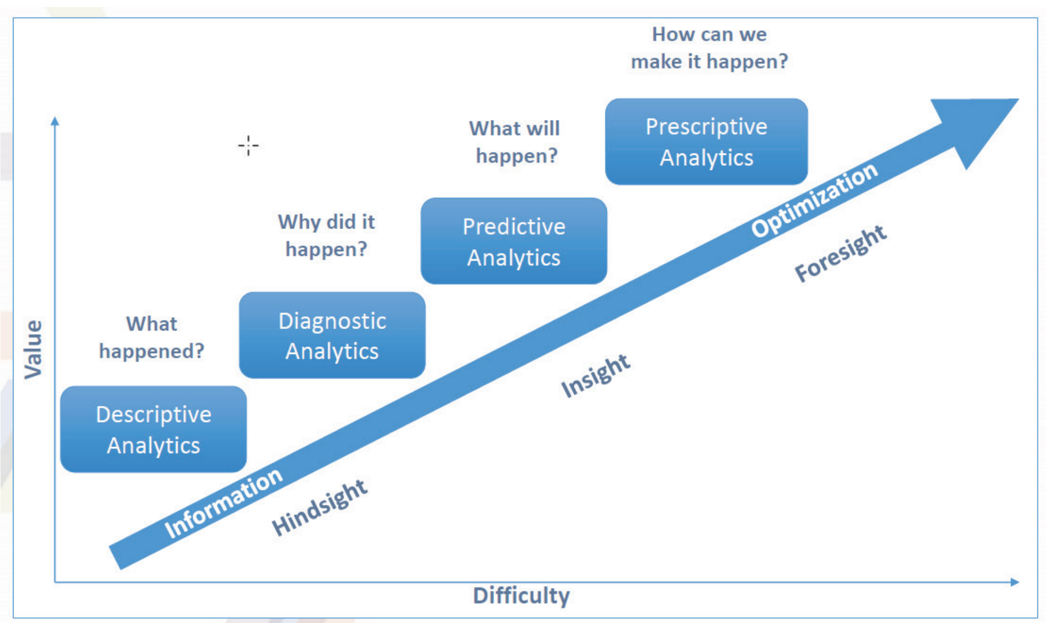
6 Data Analytics

6.1 Research focus and methods

The data analytics LOE focused primarily on the possible second and third order decision-making impacts that the AV technology could inform during the project. This LOE explored in detail three specific use-cases that were of value to JBM-HH, and used evidence from field observations, data collection, and AI applications and documents. Units of analysis included the number of terabytes, time, hours of effort, and confidence levels. The goal of this exploratory research was to characterize and determine data analytics impacts of AV technology to operations when applied at a military installation. Ridership/adoption, safety concerns, and traffic disruption/alleviation were all areas that were considered. Preliminary data analytic activities focused on these efforts.

Due to the limited scope of this project and its exploratory nature, only descriptive and diagnostic analytics tools were applied. As Figure 38 shows, future efforts are needed to further develop predictive and prescriptive analytics related to AV operation on installations.

Figure 38. This evolution of data analytics chart demonstrates the increasing difficulty and effort required for increasing value of data analytics.



Source: Denver Smart Cities Connect, April 2019 presentation

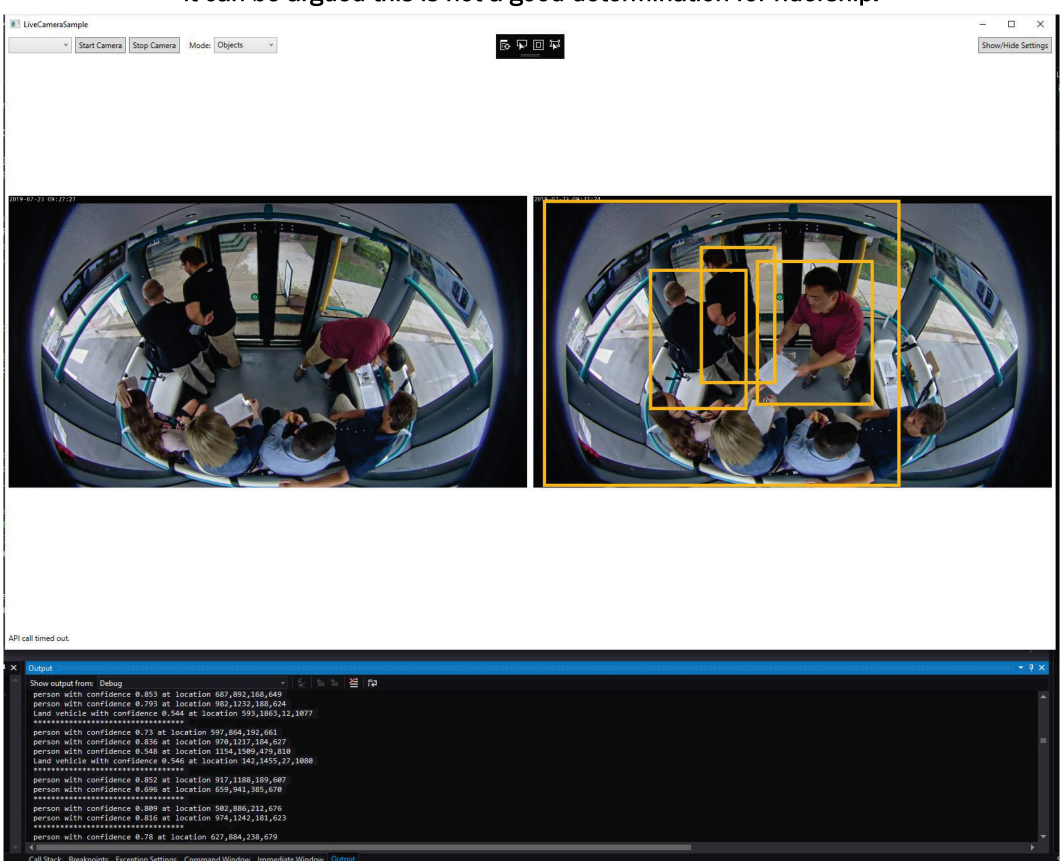
6.2 Data and findings

Three limited use-cases were explored as part of this LOE to count passengers on the AV at any given time to quantify ridership, to determine the length of vehicle queue behind the AV, and to evaluate safety steward takeovers of the AV.

6.2.1 Ridership

Ridership can be defined as the act of transporting a person from one location to another. First, ridership was examined through the use of a camera installed inside the cabin of the vehicle. Microsoft Government Azure Cognitive Services (Computer Vision) was used for object detection within a video frame. The vision model was trained to detect people using still frames from the camera with targets (areas delineated/marked in the picture and tagged as person) supplied by a human. Training the model is time consuming but does provide a good measure of accuracy, especially when confidence values are increased above 60% (Figure 39).

Figure 39. Image shows Azure Cognitive Image Processing Services in an attempt to determine person objects in frame. While this method (after AI training) may identify persons, it can be argued this is not a good determination for ridership.



Arguably this technique is not an accurate measure of ridership, because the problem is more difficult when considering operational deployment (the same person stepping off and back on the vehicle) and recognizing when the vehicle is moving versus stationary. Unfortunately, a GPS dataset was not available for this pilot. While the vision model can detect one or more person(s) in a frame, it does not know whether or not the vehicle is transporting the person without also understanding the background imagery of the previous frame. We assumed that different time stamps did not comprise an accurate assumption of vehicle movement. More importantly, if a rider left the vehicle at a stop and later returned to the vehicle, the object detection could only recognize the presence of a person object, not a unique individual object. Therefore, ridership numbers could be inflated in this manner because there was no mechanism for determining whether or not it was the same person riding in the vehicle, or a new individual. Therefore, the safety steward would be counted as a new rider every time he stepped off and reentered the vehicle.

Training the model to recognize distinct individuals brings into question privacy and security issues. In addition, the placement of the camera inside the AV was not optimal for viewing individual faces, which would be essential for individual recognition. Most images from the cabin camera show the top or back of the head. It is recommended that additional data be used to help with ridership identification, such as GPS, as well as an additional camera in the vehicle and onboard processing to determine unique individuals if ridership is to be determined through cognitive vision. Another option is to integrate the boarding process with GPS and camera or facial identification technology.

6.2.2 Traffic analysis

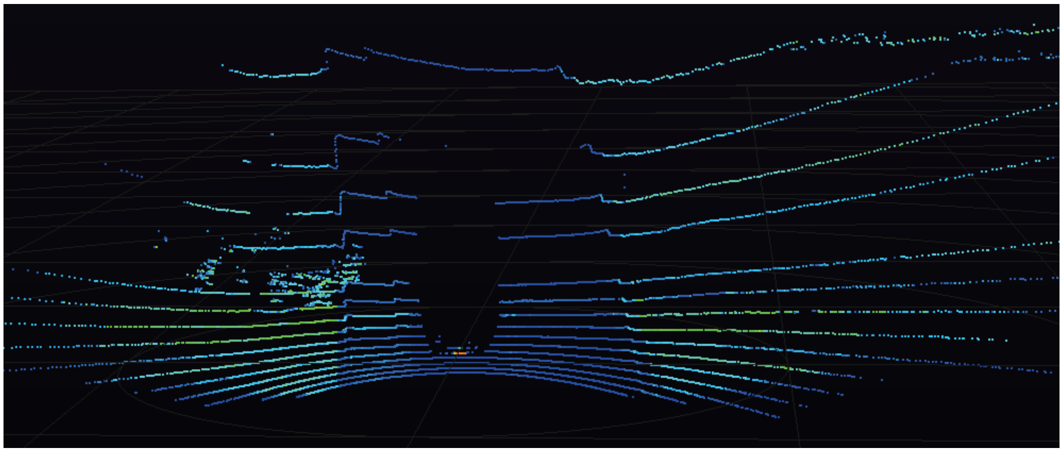
The second research question focused on traffic disruption or alleviation on the installation. It was reported that traffic queues were forming behind the AV causing traffic disruptions. From empirical observance, this could have been attributed to the cautious nature/programming of the Olli AI. When the vehicle sensed an object within close proximity (using LiDAR and radar sensors) it was programmed to reduce speed to avoid collisions. This was logical. However, if a vehicle tailgated the Olli, the AI response was to slow even further, causing more delays and buildup of queues following the vehicle. (It should also be noted the vehicle's programmed speed was slower than the normal traffic limit.)*

Measuring vehicle queues also proved a challenge with the existing camera placement. Determining queuing behind the vehicle requires a clear line of site from a top down view. While there was a top front and bottom front camera placed on the vehicle, there was only a bottom back camera mounted on the rear. The vantage from this angle only showed the car immediately following (unless the vehicle turns, thereby providing a different angle) so that other cars following the initial vehicle are obstructed from view. (Although LiDAR was also considered to investigate this problem, it had similar issues. There is a LiDAR sensor mounted on the back rear of the vehicle. However, LiDAR has a limited range of visibility and "fans" out from the source making it difficult to see any additional vehicles behind the first vehicle, especially when the first vehicle is large so that it absorbs the laser return.) See Figures 40 and 41.

Figure 40. Showing camera angles only at the bottom of the vehicle. Determining queuing behind the vehicle is difficult from this vantage point.

* Vehicle queues occurred so often that the safety stewards had an informal contest to see who would end up with the longest line of vehicles behind the Olli.

Figure 41. Showing LiDAR placement from the top of the vehicle rear facing. LiDAR creates an empty space behind the laser scan for the first vehicle making it difficult to measure other vehicles behind the first vehicle in queue.



6.2.3 Safety analysis

Another analysis was performed to review safety incidents. Data mining review by time/location for incidents involving safety steward takeover of the AV were captured. Determining edge computing use-cases that are most beneficial to installations for real-time analytics development and feedback for engineers will optimize enterprise data architecture design. Figures 42 and 43 show an incident in which the steward took control of the vehicle before the onboard processing could slow or stop the vehicle. Mining the data for time and location provides a valuable feedback mechanism for safety engineering.

Figure 42. AV video capture showing LiDAR of tractor-trailer blocking roadway. These data can be used to validate safety concerns for vehicle behavior.

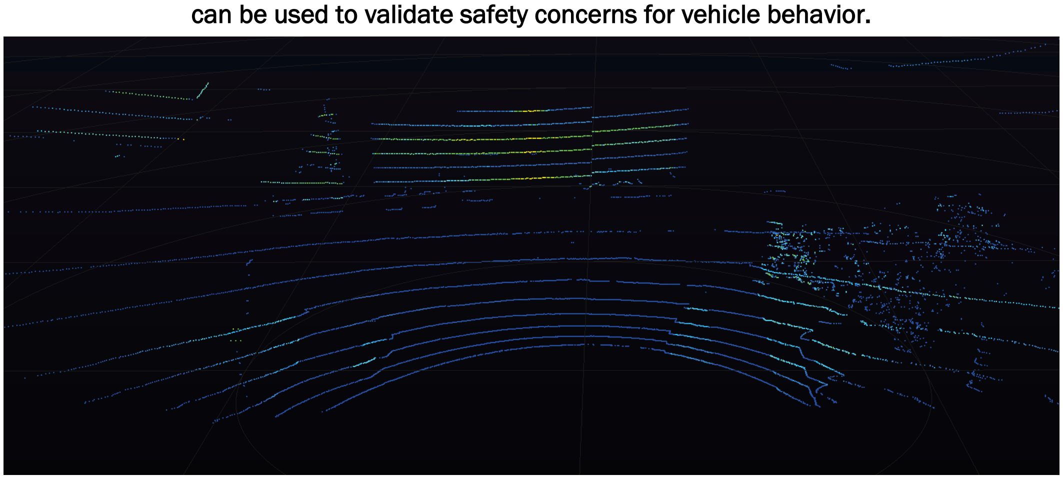


Figure 43. AV video capture showing camera of tractor-trailer blocking roadway as it is backing into a dining facility loading dock on JBM-HH.

6.3 Results and recommendations

The following recommendations and key results are based on the data analytics LOE. It is important to recognize that these are based on a single case study deployment of a single AV type on one military installation. However, many of the findings were generalizable into the following key considerations.

- AV sensors and technology are deployed to prioritize and optimize data gathering and decision-making for vehicle maneuver and navigation. Most of the AI and data integration software for this purpose are proprietary products.
- Raw sensor data from AV LiDAR and cameras were processed into video feeds for visual assessments and review; however, this was not done in real-time and requires large data storage capacity for high-definition (HD) video files. Video analysis of safety steward interventions proved challenging as searching accurate time stamps for interventions and viewing various sensor data to fully understand context was extremely time consuming.
- ERDC developed a framework to count passengers onboard the AV with acceptable reliability using AI and Cognitive Services.
- ERDC attempted to use Cognitive Services to develop an AI framework to determine queue length of vehicles behind the AV; however, the external camera location on the rear of the vehicle was too low to do so

with acceptable reliability. Further research is needed to determine if a camera on top of the AV or remote sensing is feasible for real-time queue detection.

- Data mining review by time/location for incidents involving safety steward takeover of AV are possible. Integration of GPS or other location data is essential for real-time data analytics.
- Edge computing use-cases that are most beneficial to installations for real-time analytics should drive future investment in AI and supplementary sensor integration into current AV technology.

7 Human Factors

7.1 Research focus and methods

The human factors LOE focused primarily on the interaction between people and the AV. Driving on public roads is a social endeavor (Vinkhuyzen and Cefkin 2016), so we wanted to empirically document the introduction of the automated shuttle onto Joint Base Myer-Henderson Hall. The most obvious relationship was between the Olli and passengers, but researchers also examined responses of non-riders to the AV. The project surveyed people's reactions to the AV to discover their trust in the autonomous vehicle, and to gauge peoples' reasons for acceptance or rejection of the shuttle.

A previous AV study at Fort Bragg on the ARIBO self-driving vehicle examined users' perceptions of trustworthiness, intelligence, level of automation, safety, and comfort (Schaefer et al. 2018). Through a survey of riders, their study found a general trust in the automation, which increased when more people could observe or interact with the AV. However, those researchers did not know if the trust were due to military riders having overall confidence in any technology the Army would bring on base. Additionally, their survey had a low response rate. This work builds on that pilot, while overcoming the limitations through broader survey methods and demographic questions intended to detect bias by age and work (e.g., higher trust in the AV because the respondent works for the DoD).

7.1.1 Surveys

The performance metrics examined in the project were: trust in autonomy, basic demographics, and participants' perceptions of safe operations. To collect these data, we created a 14-question survey approved through the Human Research Protection Program of ERDC (see Appendix K). The first six questions elicited general demographic information and the participant's general experience with AV. Questions 7-11 asked about the participant's perceptions regarding Olli using a 7-point Likert scale, including the machine's intelligence, safety, trustworthiness, comfort, and its use on base. These questions follow earlier studies that discovered when passengers were given the option to take control of an AV, they did so more often than necessary, indicating a lack of trust in autonomy (Schaefer and Straub 2016).*

* The takeovers occurred more frequently in autonomous vehicles that had standard controls, such as steering wheel and brake pedal, rather than just a stop button to override the autonomy.

This project sought to determine what level of trust passengers or observers of a vehicle had when a safety steward was present on the AV. Questions 12 and 13 asked about the acceptability of the vehicle in avoiding other objects and obeying traffic rules without human intervention, also using a 7-point Likert scale. The final question allowed for open-ended feedback.

After some discussion with Local Motors at the start of Phase 1a, we combined CERL's survey with their user experience survey. The result was a 21-question survey that was handed to participants and then collected when they finished riding the Olli (see Appendix L). Beginning 9 July 2019, researchers approached riders and non-riders alike to gather surveys until the end of the demonstration on 27 September 2019.

Additionally, Local Motors provided an option for passengers to take a web-based version of this combined survey, after riders had signed online waivers to ride the vehicle. The company also gathered physical copies of this survey when ERDC researchers were not present, or when riders signed a paper waiver instead of the online option.

For those riders or observers who were too busy to fill out a physical survey in the presence of researchers, CERL provided a fact sheet with a QR code and a web address to a shorter version of the survey that they could fill out later (see Appendix M). Although the surveys were initially created to be answered by both riders and non-riders alike, after the CERL questionnaire was merged with the Local Motors' survey there was some participant confusion (further discussed in section 7.2, "Data and findings").

7.1.2 Participant observation

Although surveys provide a quantitative measure of riders' and non-riders' perspectives, we also gathered qualitative data through participant observation. Researchers rode the Olli, informally talked with passengers, observers, and safety stewards while watching and documenting their contact with the AV. Many past studies on AV rely on modeling (Wang et al. 2018, Wang et al. 2019) and simulations (DeKort 2020, Schaefer and Straub 2016, Stayton et al. 2017). Attending to calls by previous researchers (Straub and Schaefer 2019), our pilot project allowed direct observation of the social interactions between the shuttle and numerous participants in the traffic system.

Because surveys are limited in the types of information gathered, participant observation allowed both the CERL researchers and other study contributors the space for exploratory questions and answers. This method is particularly relevant in exploratory research such as this fielding of new technology and in circumstances where we do not know much about a situation, because there are important differences between the views of insiders versus outsiders (DoD vs. non-DoD), and because the phenomenon is hidden from public view since AV are not allowed on most public streets (Jorgenson 1989:12-13). Observations were also documented by the VDOT's, the military contacts on base, and a variety of invited professionals and scholars. These research efforts provided comparative analysis between human decisions and the AV, along with triangulation of our survey results.

During the pilot, CERL researchers regularly visited the base, took fieldwork notes, and transmitted them to the rest of the team through trip reports after returning from a weekly visit (10 weeks of the 14-week deployment). The varied backgrounds of the researchers led to multiple perspectives in their observations, and the reports allowed the investigators who would be visiting next to prepare and follow up on outstanding issues. In addition to the informal interviews with passengers that elicited a broad array of answers, the metrics that were recorded during our trips included the body language reactions to the Olli and the actions of both pedestrians and other drivers to the AV on the road. Actions and reactions were confirmed with analysis of the Olli video recordings when possible.

7.1.3 Methods of analysis

Once the pilot ended and all data had been gathered, survey information was entered into Qualtrics and quantitatively analyzed using t-tests, chi-square testing, and linear regression (Fisher 1922, Yan and Su 2009). Four people said they answered more than one survey. Answers were confirmed by comparing age, date taken, and open-ended feedback. In two cases, the previous surveys were identified. The other two respondents might have taken earlier surveys that were removed because of incomplete data; therefore, they were left in the results. The two confirmed instances also remained in the analyses to gain a temporal perspective from the same passengers.

Field notes, trip reports, meeting summaries, and contractor documentation were gathered and collated. These disparate documents were then sorted through componential analysis (Spradley 1980), a methodology that has served many types of qualitative and mixed methods research (e.g., Phillips 2014 for disaster studies). First, riders and non-riders were sorted into specific demographics (or domains) – those who live or work on base, those working for the DoD and living off base, or respondents who do not work for the DoD. Second, a taxonomic analysis further refined our categorical domains by slicing our demographics further to compare and contrast factors such as whether particular populations had previously ridden the AV, or the age of those who had ridden versus observers. Once a taxonomy of riders and non-riders was created, the components of cultural patterns were sorted through using the domains, allowing us to integrate the findings across our varied sources and between both quantitative and qualitative approaches.

7.2 Data and findings

The diverse methods of gathering completed surveys provided mixed results. CERL researchers and Local Motors gathered 109 physical surveys, but six of those had to be removed because only one side of the questionnaire was completed. Local Motors collected 90 online surveys and 39 were removed because of incomplete answers (i.e., at least five questions were unanswered). The rate of return on the fact sheet with a link to the survey through QR code had only three responses. This survey was created on SurveyMonkey using their basic survey, which only allows 10 questions due to this provider being a Federal government approved vendor. Because the fact sheet survey only provided a smaller subset of 10 questions, and we only received three responses, we did not use those results. The low rate of return confirmed previous researcher's experience at Fort Bragg that online surveys garner less results.*

We gathered a total of 154 usable surveys. This included 101 responses from Phase 1a, the invitational period from 19 June to 12 August, and 53 surveys from the open Phase 1b from 13 August to 27 September 2019. The questionnaires were filled out by safety operators (N=3), people who live or work on the base (N=48), workers for the Department of Defense who live off base (which included military, N=19), and respondents who do not work for the DoD (N=84). There were 32 non-riders and 122 riders (including safety stewards). None of the passengers, other than the safety stewards, had ridden Olli more than twice, and one observer claimed to

* Personal communication, 26 April 2019.

have been a passenger 3-4 times; perhaps they had seen Olli operating that many times at Joint Base Meyer-Henderson Hall.

The problem with combining the two surveys is the marketing questions from Local Motors assumed that people had ridden the Olli. The CERL survey was created so that either riders or non-riders could take it. The combined surveys created some confusion, as Local Motors' Question 5 asked if the vehicle was comfortable. Some non-riders answered that question and then read on to CERL's Question 17, which had been reframed as, "If you were not a rider: the vehicle appeared to give a comfortable ride," with a 7-point Likert response of Strongly Agree to Strongly Disagree. This created misunderstandings, especially since respondents using Local Motors online survey could not return and change their previous answers. As one person's feedback noted, "The survey interface does not allow me to easily go back and review the questions and my answers." For purposes of analysis, CERL maintained the original language for Question 17 and combined responses so both riders and non-riders responded to perceived comfort in the same question.

Respondents included military and civilian personnel who were on base for a variety of reasons. Many of the surveys were gathered from people invited on base by the NVRC to see the operation of the Olli in person. Although there was a low level of ridership from military personnel (83 of our riders did not work for the DoD), we did gather valuable information about this minority of DoD riders and those passengers who live or work on base (see section 7.2.2, "Low ridership").

7.2.1 Intelligence, comfort, and trust in the AV

Both riders and non-riders either agreed (48.7%) or strongly agreed (24%) that Olli was intelligent. Of those respondents who only somewhat agreed that the AV was intelligent (16.9%), gave reasons including the machine had stopped without reasonable cause, it stopped a little past the stop sign, or it stopped too far away from stop signs and cars. Additionally, when the safety steward took control of the vehicle at times (including manual stops for pedestrians in crosswalks), this action resulted in riders questioning Olli's intelligence. Interestingly, one of the safety stewards would use the emergency brake to stop the AV well before the crosswalk if it were occupied. He said, "There are many times where I pull the emergency brake early, though I know Olli will stop. That's to give people [pedestrians crossing in front of it] their space so Olli doesn't scare them by getting too close before stopping." Most of those who neither agreed nor disagreed with the vehicle's intelligence were non-riders (N=14 out of 16).

Riders perceived Olli as mostly comfortable, with 72.7% of respondents strongly agreeing (N=25) or agreeing (N=63) that the vehicle was comfortable. For those who somewhat agreed, or neither agreed nor disagreed that Olli was comfortable, some passengers commented on the seats/seatbelts (N=5), that it needed more room inside (N=2), that the temperature was irregular (N=1), or the stops and starts were jerky (N=2). The inconsistent deceleration and acceleration were also mentioned in surveys that rated riders' perceptions of safety as low (see below), but comfort was particularly pronounced in one comment. The rider noted that, "I sat in the back seat, which made me nauseated with the jerky and fast stops and starts. I had to move to a side seat and sit with my legs toward the front to support me. I would not ride it again 'til that was fixed."

Additional comments on comfort that overlapped with other domains, such as whether people would ride it again, were those relating to air-conditioning and heat. One notably positive response, from a mother who lived on base, reflected on the convenience of the service,

> I'd love it if Olli would go both directions down McNair Rd. This would be greatly beneficial during the "school year" months, as weather is more challenging and walking not the easiest. I will bring my two kids for a later ride.

Trust in the autonomy was mixed, with a 63.6% majority of participants either strongly agreeing (N=31) or agreeing (N=67) that Olli was trustworthy. Whereas 72.7% of respondents believed the AV was intelligent, the nearly 9% difference raises the question of why more people think Olli is intelligent rather than trustworthy. First, it should be noted that many of those who neither agreed nor disagreed that the AV was trustworthy (thereby taking a neutral perspective) were non-riders. Nearly half of non-riders (46.9%) were unsure if it was trustworthy, while only 9.3% of riders doubted the vehicle's trustworthiness—68.7% of riders either agreed or strongly agreed in the Olli's trustworthiness.

This statistically significant relationship indicates that both non-riders and riders see the AV operating in an intelligent manner, but riding the vehicle engendered a greater level of trust. Despite this, the open-ended feedback demonstrates why some riders still did not trust or strongly trust the Olli. Of those riders that somewhat agreed in the trustworthiness of the vehicle (N=29), they questioned its ability because the safety steward drove the route (N=1), it stopped far away from cars and stops signs (N=1), it had jerky starts and fast stops (N=3), and was not slowing down for pedestrians that were near it (N=1).

Previous research has shown that users of autonomous machines and robotics demonstrate higher degrees of trust when there are high degrees of communication between the AI and the human (Schaefer et al. 2017). This feedback loop is important for the operator—and in our case, the safety steward who always watched the Olli's progress on both the small monitor in front of him (which was not visible to riders), and the road. Additionally, our observations implied that knowing what the machine is doing and how it is making decisions might be critical for at least some riders.

As CERL researchers rode along with invited groups, the safety stewards were often asked questions about how the Olli made decisions. Riders also mentioned the importance of understanding what the machine was doing in their surveys. One participant noted that an improvement to the machine would be, "Verbal communication to let passengers know the stops, status, intentions."* When the autonomous vehicle itself becomes the literal driver, passengers begin to wonder about what the machine intends to do during operations.

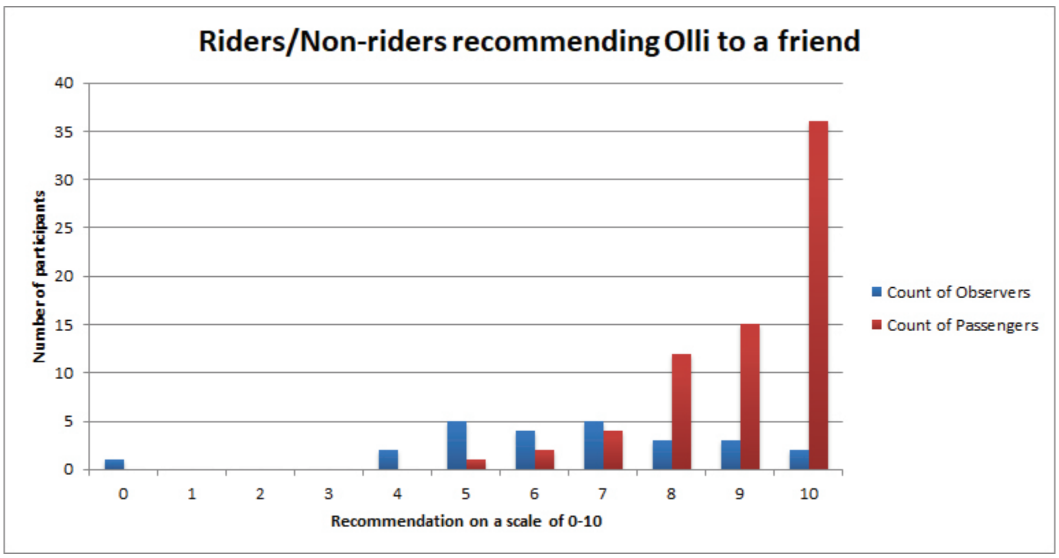
The importance of knowing the intentions of the AV was brought into further focus as another rider described how the "Safety operator should be more descriptive about their intervention vs. Olli on auto[pilot] so we can better distinguish [when Olli is on autopilot]." This rider further elaborated that "It was difficult to assess with the driving steward close to the controls," making it clear that knowing what decisions the AV was making would have increased trust in the autonomy. Despite these riders' concerns about needing more information regarding the Olli's intentions, the simple act of riding the machine alleviated most participants' concerns.

When asked, "How likely you are to recommend Olli to a friend or colleague on a scale of 0-10," there was a significant statistical relationship between those who had ridden the AV, and non-riders. Passengers were

* Seven riders made comments requesting more communication by the Olli through either voice or monitors for situational awareness.

89.2% likely to recommend on the upper end of the scale (8-10), and the three safety stewards rated it 10. While 66.6% of the observers not riding on the vehicle only recommended from 7 or lower (45.8% rated 6 or lower). Unsurprisingly, those who rode Olli were more likely to recommend it to others (see Figure 44). The likelihood of endorsement was unaffected by age of the participants, unlike other studies that found lower levels of trust in older participants (Dikmen and Burns 2017).

Figure 44. Comparison of recommendations to a friend depending on whether a rider or not. These data were gathered after the Local Motors and CERL surveys were combined; since the question was one of the added Local Motors' questions, not all participants were asked this question.



Although the hypothesis was that those people who live and work on base, and those who work for the DoD would have greater trust in the AV because it had been cleared to operate on base, our analysis found no statistical relationship between those factors. Because it is important to gain the trust of those riding the vehicle, it would be useful for future researchers to ask about levels of trust both before a ride and after a ride to see how much trust rises in passengers. Gathering such data might also provide an understanding about DoD workers' trust in base leadership's vetting of such technology, especially if there are differences in trust before riding depending on whether a civilian or military worker/family member.

7.2.2 Low ridership

While the route was being mapped, the Olli moved around the base following its programming, but people were not allowed to ride during the 3-week setup. Additionally, once Olli was opened for invitational events, a sign was posted on the back to discourage tailgaters, but was ambiguous regarding the purpose of the vehicle as a transportation option (see Figure 45). Outside signage also reflected the research aspect of the vehicle, with the logo of the programming company being shown in the display (e.g., Robotic Research, see Figure 46). Although 2 weeks later the sign was changed (see Figure 47), the notices had indicated this vehicle was for research rather than general ridership, and that impression was reflected in both survey results and feedback during a family event on base.

Figure 45. Sign posted on the back of the Olli during part of Phase 1a, because if drivers tailgated then the AV would slow down.

Figure 46. External LED on the Olli, displaying "Robotic Research," the company responsible for the programming of the autonomy.

Figure 47. Rear signage changed on the Olli, reflecting the open Phase 1b, but still not stating that anyone could ride the vehicle.

The open-ended questions in the surveys indicated some reasons for low ridership. These included the need for the vehicle to operate more hours so users would find it convenient to take the Olli to meet general transportation needs beyond the 2 lunch hours. There was also feedback saying people wanted expanded routes (including routes going in both directions), on demand ride requests, and more information about the current routes, as "I only know of Olli as it passed by." Numerous survey comments indicated that Olli needed more stops and at specific locations, especially during peak transit hours.

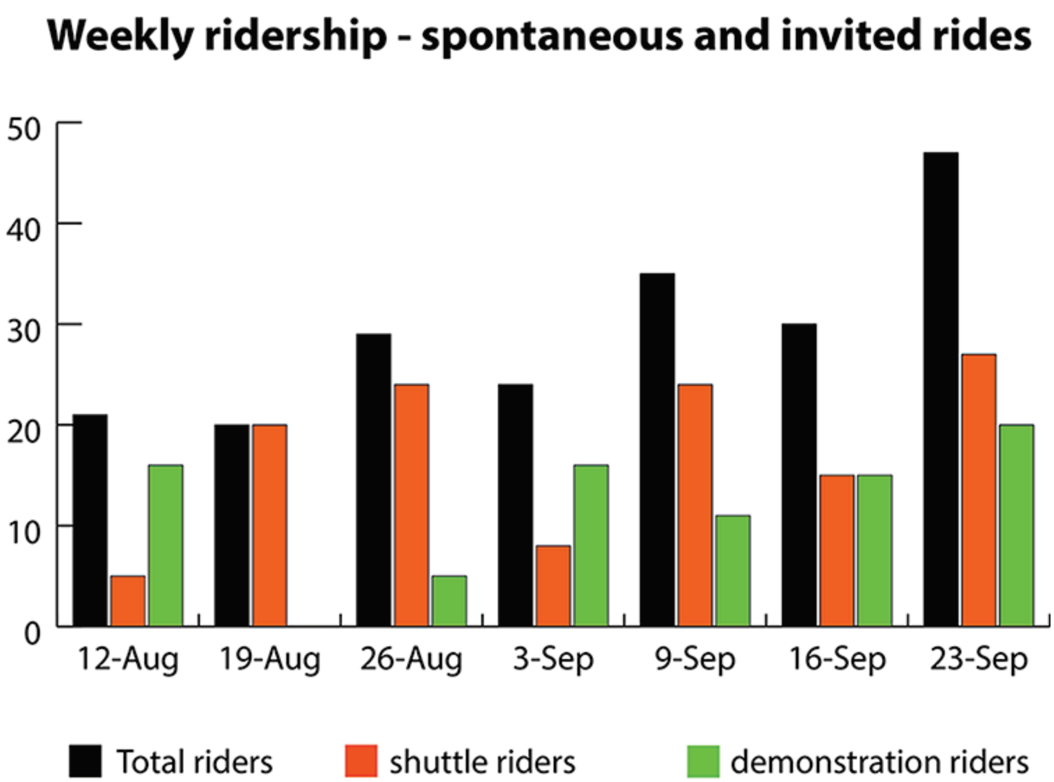
The base newspaper, The *Pentagram*, printed numerous articles about Olli leading up to the launch of the AV pilot (Appendix D). During the deployment, the paper printed additional articles and also posted the weekly time schedules. Other outreach included a poster board at each of the stops with removable schedules for prospective riders (see Figure 48). There were also examples of riders posting videos of their experiences to social media such as Facebook and TikTok.

Figure 48. Sandwich board at one of the stops showing how to register for signing a waiver online with attached schedules.

Despite this outreach, ridership for the 7 weeks of the open Phase 1b only averaged 18 riders per week, if you do not count the invited groups. During an event at the Child Development Center, the Olli was on display among other vehicles such as a police car, fire truck, and a school bus. The safety steward at the event described how many parents took advantage of the vehicle's air-conditioning, allowing him to discuss the AV with the attendees. Most people said they had seen or heard of the vehicle. However, when the steward asked further questions, attendees often said they did not know Olli was available and they were afraid of riding an AV. On learning there was a safety steward onboard who can intervene if necessary, and that the AV was free and open to the public, the visitors showed increased interest and the attendant quickly ran out of schedules.

To address the low ridership, Local Motors, in concert with base leaders, expanded the Olli operating schedule in the final 3 weeks of operations. Adding a morning route for the twelfth week, and an evening run for both the thirteenth and fourteenth weeks of increased service, ridership peaked with the combination of both spontaneous shuttle riders and invited demonstration groups (see Figure 49). Providing accessibility for prospective passengers during the busiest transit periods of the day, and a marketing push of the expanded hours in high traffic areas, such as the bowling alley, resulted in higher ridership. The next section addresses the question of whether more riders increased overall perceptions of the AV's safety.

Figure 49. Phase 1b ridership comparisons of open shuttle spontaneous riders and number of invited demonstration riders.



7.2.3 Perceptions of safety

As comments from attendees to the Child Service Center Event indicate, prospective riders fear the unknowns of an AV. After talking with many of the attendees, the steward was able to alleviate their concerns. However, a later experience by one of the safety stewards with an observer highlights the challenges of making AV available to the broader public. According to the steward, he had exited the Olli to allow a woman and her children off the AV at the Commissary. An elderly man standing nearby asked, “Why are you riding in that thing?” The uniforms of Local Motors consist of a t-shirt with a small logo; therefore, it was not clear that the steward was actually monitoring the AV.

Because the Olli was somewhat ahead of schedule, the steward engaged in conversation, telling the man that he was employed by Local Motors and that he rode the vehicle to make sure that nothing went wrong. The retired military commander asked, “Have you crashed into anyone yet?” When the steward asked why the observer thought the AV would hit someone, the man replied that the technology is being rushed without proper testing and all people care about is getting the vehicle on the road to make money. As the steward said,

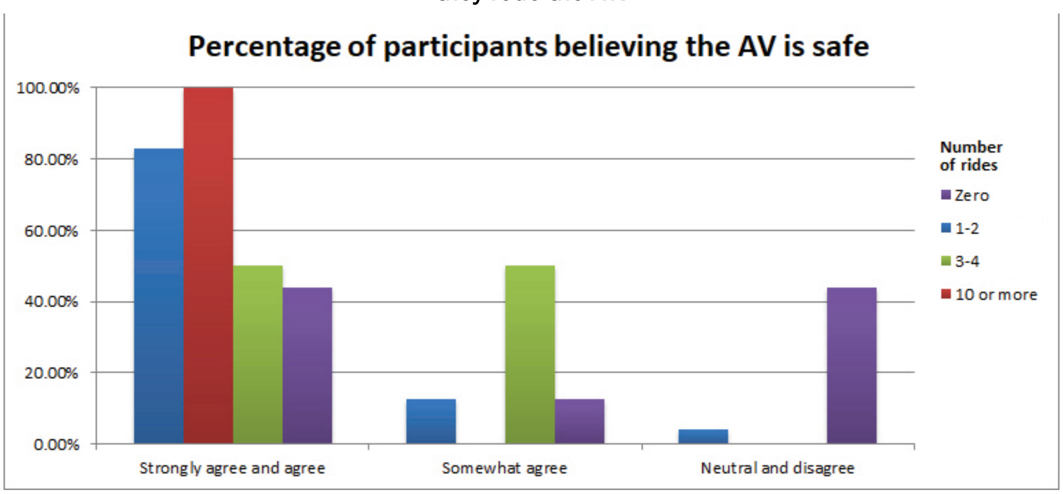
> I began explaining that this is a partnership between Local Motors and the base to gather and provide data on how Olli operates with safety always being the number one priority, and that the vehicle is free to ride. This debate between the two of us went on for five or so more minutes, with him providing insight on why it can’t be as safe as advertised, and me rebutting each claim with data points, explanations, and demonstrations – as I’ve done many times before. He stopped bringing up his concerns about Olli’s safety, which I took as a sign that he was reassured and might hop on for a quick ride. It was time to leave as we were back on schedule at this point so I asked if he would like to go for a ride that’ll take no more than a couple of minutes, and drop him off back at the commissary. He waited a couple of seconds, looked at Olli then back at me, and smiled. He then looked me in the eye and said, “Never,” and walked off. (Personal Communication 13 September 2019).

One of the points of contention raised by the military retiree was that the machine cannot take in all the information, process it, and then drive like a human. The steward countered that Olli takes in more than enough information through all of its sensors, such as LiDAR, cameras, and GPS.

Because the vehicle is operated by a computer, it can process all of the data much better than a human being could sort through that information. However, the prospective rider was clearly unconvinced.

The experiences of Olli riders and observers as posed through the survey provides greater insight into whether a ride on the AV completely convinces skeptics. There was a strong statistical significance between the numbers of times someone had ridden Olli and whether they agreed that the vehicle is safe. Passengers who had ridden the AV one to two times either agreed or strongly agreed in the safety of the AV 83% of the time. Riders somewhat agreed it was safe 12.7% of the time, which was comparable to those who had ridden it zero times (12.5%). However, of those who had not ridden the machine – 10 times the number of passenger respondents – 34.4% neither agreed nor disagreed that it was safe (see Figure 50). Although those people who have not ridden the Olli question its safety, the perceptions of riders draw safety into even sharper focus regarding concerns that the general public has with AVs.

Figure 50. Safety as perceived by participants depending on the number of times they rode the AV.



Examples of comments raised by riders who said they somewhat agreed that Olli was safe include that it was "skittish" by not starting and stopping smoothly, and "the vehicle did not slow down for two pedestrians who were not in the crosswalk but were very near to the vehicle." The theme of the AV not stopping or slowing down for people or objects was raised multiple times in the open-ended question section of the survey. Examples include, "On the question about Olli avoiding traffic and other obstacles without human intervention, it mostly did not do that—i.e., the operator had to intervene." However, the passenger's perception of how far away Olli should stop when a pedestrian crosses in front of it depends on the subjectivities of personal space.

The subjective nature of place and space is highlighted when our quantitative analysis demonstrates that most riders thought the Olli was safe and that it did stop without human intervention. However, the challenge of dealing with subjective personal space must be addressed by AV producers if they wish to see more acceptance of their vehicles on the roads. As one respondent noted, "I'm a bit more aggressive toward safety than Olli," highlighting the social nature of space, and how closeness affects perceptions of comfort and safety (McLaughlin 2016).

One example explicitly demonstrating the links between space, riders' perceptions of safety, and Olli's operations was an incident involving a semi-trailer backing across the road in the AV's travel path. On 23 July, at 10:06:25 am, the safety steward pulled the emergency brake as the Olli continued towards the truck crossing in front of it. The operator flagged the incident so programmers could later examine the details,* and the steward's quick reaction had an impact on five out of nine passengers that day, who later in their surveys only somewhat agreed that Olli was safe. One passenger wrote that, "Olli failed to detect semi-trailer entering the roadway, which required human intervention to avoid collision." The perception was the AV did not "detect" the object, yet the programmers discovered the AV would have stopped before colliding with the tractor-trailer. Both the safety steward and the passenger (reading the operator's takeover) reacted because they did not think Olli was going to stop.

Although it is better to be safe, reacting before the software can engage is common in current autonomous operations. Previous research discovered unnecessary autonomous interruptions using simulations with two different vehicles where passengers could interrupt the AV, one with a steering wheel and brake pedal, and the other with a red stop button. Before the passengers started the simulation, they took a survey that indicated more people trusted and had less anxiety in vehicle with traditional controls. However, they were also more likely to intervene in the autonomy when seated behind

* Unlike the above mentioned courtesy stops, this takeover indicated the safety steward did not think it would stop as he flagged the incident for the programmers to examine. One of the concerns leading him to question the AV's continued forward trajectory might have been the recent rain (see p 49), as puddles and rain on the sensors sometimes interfered with incoming data.

the traditional controls, rather than when they just had the red disengage button. This demonstrated that passengers on AVs were more likely to intervene in AV operations when seated behind familiar controls, though they had less trust in the autonomy when faced with only the disengage button (Schaefer and Straub 2016). The implications for our example of the backing tractor-trailer is that in high risk environments (e.g., the open road), both AV operators and observers err on the side of caution. If there had been more vehicle-to-safety steward communication indicating that Olli was going to stop, the operator could have allowed the machine to halt on its own. The passengers would have also seen the vehicle deal with the obstacle on its own, thereby raising their perceptions of safety.

As mentioned above, riders commented on the safety steward taking control to avoid traffic and other obstacles. Their observations included what occurred within the vehicle, and what was happening in the broader operational environment. Driving requires interaction with other people beyond just following rules of the road, whether that includes waving for someone to go, and thereby yielding the right of way, or just making eye contact to confirm the other driver has seen you before making a turn. The social dimensions of roadway communication must be addressed by AV producers. Other driver and AV interactions are discussed, but a polite safety steward's actions highlights the "courtesy problem."

While one CERL researcher was riding Olli, he noticed the safety steward pulling the emergency brake farther away from a crosswalk as pedestrians were crossing or getting ready to cross. After asking the steward about it, he replied, "There are many times where I pull the emergency brake early, though I know Olli will stop. That is to give people [pedestrians crossing in front of the AV] their space so Olli does not scare them by getting too close before stopping."[*] In survey comments, one passenger directly addressed this by stating, "[Regarding] Question # 18: Manual stop for pedestrians in crosswalk." Ironically, the manual stopping early for people in crosswalks by one safety steward was out of politeness, but it had the effect of reducing the AV's riders trust in Olli—even though it may have raised non-riders trust in the machine.

Straub and Schaefer (2019) discuss the "courtesy problem" as the social rules of the road, often enacted through local cultural understandings of etiquette using nonverbal signals to yield or forecast intentions. These

[*] personal communication 13 September 2019.

capabilities are human interactions that rely on waving someone through an intersection, activities we often saw the safety steward perform, but Olli is incapable of performing with only its left and right turn blinkers. As one rider noted, “[Olli] needs the ability to understand human behavior in other vehicles.” Robotic mastery of informal communication will be critical for the success of AV, and researchers are currently working on AV “Intention Indicators” (Vinkhuyzen and Cefkin 2016), but even the most successful machine-human interactions can be perceived negatively (McLaughlin 2016, pp 48-51).

7.2.4 Unsafe conditions from other drivers

As one safety steward noted, “Olli is programmed to operate like a student driver—very conservatively.” This places the riders’ and non-riders’ mostly positive perceptions about safety in context: with negative views only standing at 13% of participants somewhat agreeing and 12.3% either neutral or disagreeing that the AV is safe. Riders noticed and commented on its 12-mph movement saying, it “needs increased speed,” and “higher speed.” Non-riders also observed its low-speed operations, saying it needs to move faster (N=2), and that it should provide “knowledge for other vehicles to know how long the vehicle stops, and when it will move again.” The remarks by observers indicate the slowness, and a lack of vehicular communication, with 25.3% of non-rider respondents saying Olli was a purported safety hazard. Other drivers did not help the situation.

Some motorists took advantage of the autonomy, knowing the vehicle would stop when they cut it off. This occurred numerous times, as captured on the Olli-mounted video cameras, and as also documented by both the VDOT’s and CERL riders. One researcher observed Olli stopping at a three-way intersection, and after starting again, being cut off by a vehicle that quickly turned in front of it. This was then followed by another vehicle from the same direction turning in front of it before it was able to start (see Figures 51 and 52). The conservative nature of the autonomous low-speed shuttles’ programming has been mentioned by other authors (Eliot 2017) and was noted before the Olli pilot began at Joint Base Meyer-Henderson Hall.

Figure 51. Olli stopped before the stop sign, then proceeded, and was cut off by this vehicle. It stopped right before the pedestrian crosswalk and a red jeep is seen at the stop sign to the right.

Figure 52. The AV started driving (note it is now in the crosswalk) and the jeep cut it off. Both this and the above image are from Olli video screen captures.

When discussing other AV pilots, one Robotics Research engineer told us that drunk people would jump in front of the AV to see if it would stop during a separate Olli deployment in Adelaide, Australia.* Removing the problems of a lack of self-preservation from the equation, our research demonstrates that once people learn an AV will stop for them, some will take advantage of the situation (cf. Eliot 2018). Unfortunately, broadcasting the intentions of the machine more clearly might also result in more people taking advantage of the autonomous system.

It is ironic that, even though potential AV consumers show a mistrust of the technology and producers call for more communication tools (e.g., Blanco 2018, Cefkin 2020), broadcasting outward indicators of the vehicle's intention may result in more people taking advantage of it. Local Motors, ERDC, and the VDOT researchers all raised concerns about drivers passing Olli during stops. The VDOT and Local Motors recommended educating the police to have them aggressively enforce the rules of the road, but no citations related to Olli interactions were documented.

7.2.5 First and last mile transportation options

Due to military security measures, many people who live off base either drive to work, travel via public transit, or take a taxi/commercial ride share. Those traveling by private vehicle park on base, but others must disembark from their transit option at the gate, go through security, and then walk to their work location. This last mile of foot traffic is especially prevalent for Service members, who often own only one vehicle per household. The first and last mile challenge is a concern for the VDOT.†

The need for a quick ride during the first mile when leaving the base, and the last mile when entering for local transportation options was consistently raised by both passengers and observers during the Olli pilot. The non-passengers (11.7% of them) said they wanted more stops, had requests for stops at a specific location, or wanted the AV to run more hours. Additionally, respondents asked researchers whether the vehicle would be operating during the winter, and if stops would be expanded to one of the other gates, indicating that people were interested in riding if the shuttle was convenient and addressed their specific needs.

* Personal communication, 29 May 2019.

† Personal communication 28 January 2020.

Riders mentioned their trust in the safety of the vehicle, and also described how expanded routes could better serve the on base population. Passengers requested that the Olli run in both directions, rather than drive to one end of the base and then return to the other by a different route (see Figure 53). This circular track did not follow the same path in both directions. The route prompted one transit user who wanted to continue riding regularly from the base entrance to work, to ask, “How do I take a return trip down the hill?” Another passenger recommended that, “One vehicle could operate on half the route, while the other vehicle operating on the second half allowing transfers to make the return quicker and more efficient.”

Other people’s comments demonstrating interest in the shuttle for solving the first and last mile challenge included requests for on-demand rides, and requests for both wheelchair and bicycle access. Even with only two shuttles, there was some overlap at the middle of the route, so one researcher was easily able to travel from one end of the base to the South Gate, get lunch, and then return only 20 minutes later. However, with most of the deployment – 11 out of 14 weeks – only operating during a 2-hour lunch period, the first and last mile possibilities were not tested to any focused degree.

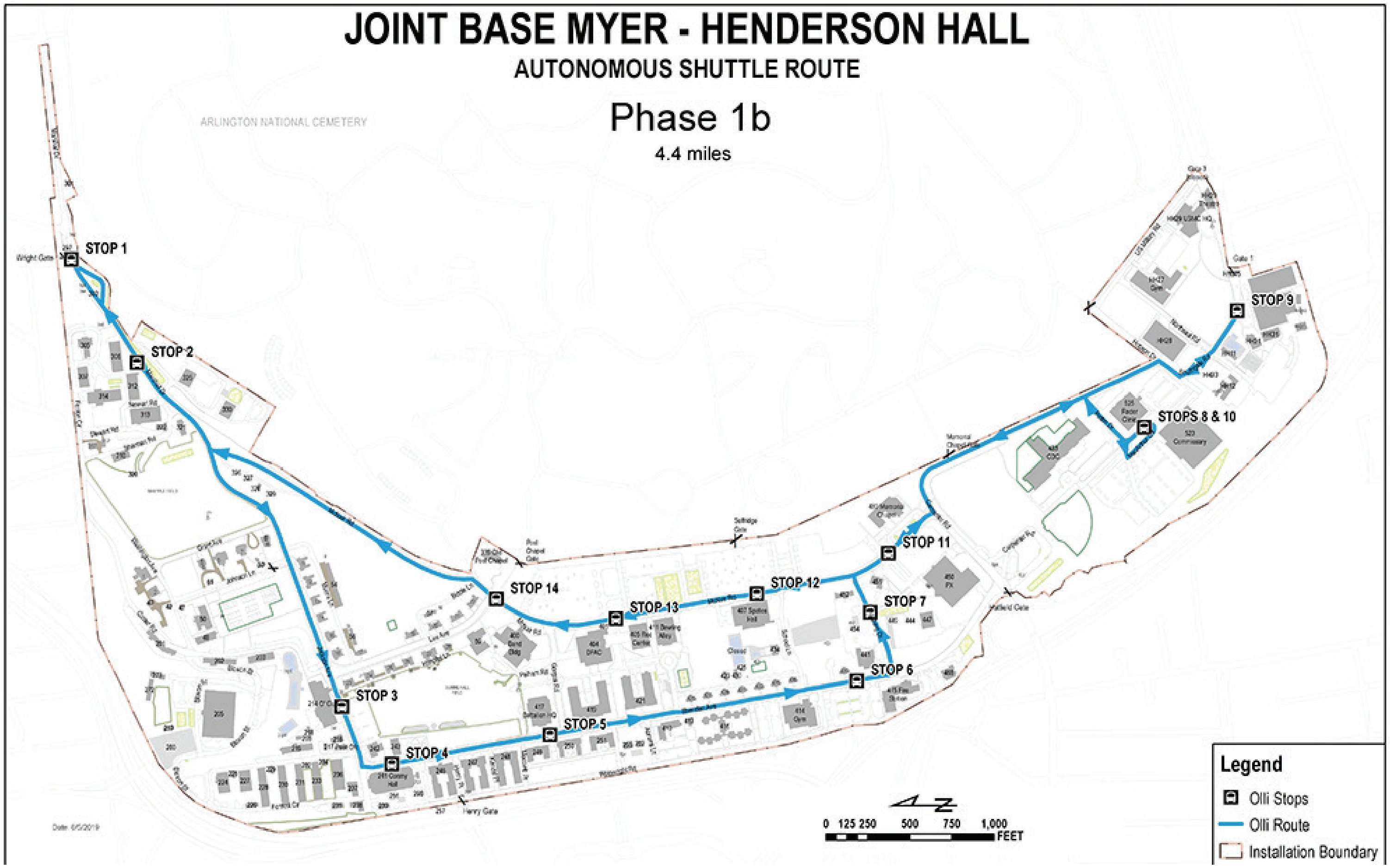
7.3 Results and recommendations

The following recommendations and key results are based on the human factors LOE.

Future AV pilots should determine transportation goals, user origin/destination, and mobility patterns before implementation. Overall ridership was much lower than expected but this may be attributed to the limited duration of deployment, lack of advance marketing or advertising in multiple venues, and the challenges in changing human habits and behavior. The lower trust in the vehicle by non-riders indicates that one solution to overcome hesitance in using the technology is to make shuttle service convenient and well-advertised, so more ridership creates a groundswell of viral marketing.

Future researchers should continue to analyze how trust is gained through the use of new technology. This can be done with short pre-ride and post-ride surveys, asking about levels of trust before and after the use of the AV. Detecting before and after ridership perceptions on the safety of the AV would allow insight into the differences between participants’ experience, whether riding or not.

Figure 53. The JBM-HH Olli route, showing the one-way direction of the vehicle that means passengers who want to get on at Stop 3 and go to the Commissary to get groceries (Stops 8 and 10), must travel all the way around the circuit to return to their starting point.



The issue of allowing the AV to do its job without safety steward interference is complicated. If the employee intervenes too often, then passengers get the impression the machine is unsafe. Yet, the programming of the Olli to halt well before crosswalks and the stop line results in more drivers cutting off the AV, which slows the shuttle, making an uneven ride. If the machine continues to be programmed conservatively for safety, then the laws must also be upheld, which would mean local police should cite infractions for other drivers passing and cutting off the AV.

Clear communications are crucial to encourage widespread ridership; this should especially include continuous public engagement beyond initial media press release, e.g., through the use of social media, QR code, sandwich boards, flyers, newspaper ads, etc. Even better is to partner with the tools that potential riders already use for receiving AV shuttle information (e.g., “Rider” app, “Transit” app, “Google Trip Planner”, etc.). Additionally, when the vehicle is in “research” mode (whether the vehicle is being driven to map the route before operations, or is only accepting invited ridership), the display on the vehicle and signs should state when the general public will be able to start riding. We also recommend that safety operators and research team wear uniforms that clearly mark them as people in an official capacity who can provide information to prospective riders.

8 Program Integration and Mission Assurance

8.1 Research focus and methods

"Program integration" refers to the synchronization and arrangement of plans and actions to engage as a whole. Program integration serves as the resource and knowledge integrator to both contextualize and refine, and generalize and expand on the results of this research project to take the greater DoD perspective, and to apply those results to achieve broader national security objectives and to serve the needs of related missions. Mission readiness and mission assurance concepts provide the research focus through which program integration is assessed.

This chapter examines resilience impacts and implications of the project through the lens of mission assurance and mission readiness. The DoD operationalized resilience through formal national policies on mission assurance beginning in 2016. These polices are dynamic and mission readiness at the unit level is integrated into the various areas of the mission assurance framework. Mission Assurance (MA) is a process to protect or ensure the continued function and resilience of capabilities and assets critical to the performance of DoD Mission-Essential Functions (MEFs) in any operating environment or condition (DoDD 3020.40 Mission Assurance 2016; DoDI 3020.45 MA Construct 2018). The research team employed observations and surveys to evaluate the AV project process and outcomes related to mission assurance from the two Olli vehicles at JBM-HH.

The methodology and findings in this chapter are a synthesis of the pilot study results as well as specific interviews conducted on 18 September 2019 at JBM-HH with representatives from the PAIO/NEC. These offices were the primary leads and points of contact and integrators for the installation from April to October of 2019 and had direct knowledge of all facets of the AV pilot operating on the installation. These findings incorporate candid feedback using the 17 areas of mission assurance that DoD has established related to resilience. These 17 activities are assessed in relation to how they ensure and protect MEFs for the installation. Information was solicited by asking the following key question in each MA area: "How did the Autonomous Vehicle Pilot impact ___________ (insert MA area)?" with follow up questions and discussion based on the answers.

8.2 Mission assurance areas and findings

8.2.1 Adaptive planning

The working definition for adaptive planning in the context of this technical report is

> the time-sensitive development of joint operation plans and operation orders for the deployment, employment, and sustainment of assigned and allocated forces and resources in response to an imminent crisis (HQDA 2018).

This definition applies Army crisis action planning at the installation command level where operational flexibility is needed. Adaptive planning is also implied in the concept of mission command that uses mission orders to empower adaptive and agile leaders with the ability to conduct operations even amid uncertainty.

The project team made changes to the employment of the AVs and the allocation of the provided transportation services periodically due to initial uncertainties. Before the AV arrived on JBM-HH, the installation was forced to think outside normal operations to consider autonomous technologies that fed into adaptive planning. While subjectively not rising to the level of crisis action planning, quick adjustments were made to the original plans using expedited decision-making aligned with the JBM-HH adaptive planning process. Examples include the adjustment to times and routes of the AV based on reduced battery life in the first weeks of operation, safety concerns with high volumes of traffic congestion during the morning and afternoon peak times, and survey results related to when and where riders wanted to go after the first 3 weeks of operation. Lunch hour was ultimately targeted to accommodate travel to food vendors, and because traffic levels were reduced from the morning and afternoon rush hours. This adjusted time of transportation services by the AVs still allowed substantive observation of AV interactions. As new food options become available, anticipated food routes may need reviewed again to expand from current drop-offs at Panda Express, Subway, and Starbucks.

The adaptive planning was done within the S6 and PAIO, staffed and approved by the installation commander when appropriate, and then pushed out to others for implementation. One example went even higher than the installation commander when a request from the Chairman of the Joint Chiefs of Staff (CJCS) and White House was received to use the AVs for the

General Milley change of responsibility ceremony to become the new CJCS that occurred on JBM-HH on 30 September 2019. The planned route was to accommodate AV passengers from the Hatfield Gate to the parade field. While a plan to use the AVs for this event were made, inclement weather ultimately canceled AV use for the event.

Adaptive planning considerations required JBM-HH staff to think through leveraging AVs during a crisis event to continue MEFs. Some ideas generated will be discussed in the following MA areas; however, due to the temporary nature of the AV pilot, incorporation of AVs into formal installation adaptive planning to identify related critical tasks, assets, and systems did not occur.

8.2.2 Anti-terrorism (AT)

AT is defined as defensive measures used to reduce the vulnerability of individuals and property to terrorist acts, to include rapid containment by local military and civilian forces (JP 3-07.2). AT considerations included physical, operational, and cybersecurity threats. Cybersecurity is discussed under MA area #6 in this report. MA area #13, insider threat, of this report also includes physical and operational security concerns identified specific to that area. Terrorist acts related to AVs on installations could include physical or cyber-attack of the AV, AV related systems, or people onboard; physical attack using the AV to damage personnel or property; using the AV as a delivery system for an explosive or other hazardous device; or any combination of these. These concerns were addressed by ongoing AT measures and Force Protection Conditions (FPCONs) used by the installation in accordance with contemporary threat assessments at both the local and global levels. JBM-HH made no specific AT policies or amendments to existing policies and procedures as a result of the AV pilot, largely because the AV operated only within the installation boundary and security perimeter fence. If an AV were to begin transportation service that continually went on and off the installation carrying passengers from other publicly accessible and non-secure areas, a review of the entry control point procedures would be conducted and adjustments made with AT considerations guided by the specific technology and ridership characteristics.

8.2.3 Chemical, biological, radiological, and nuclear (CBRN) survivability

CBRN defense is defined as measures taken to minimize or negate the vulnerabilities to, and/or effects of, a chemical, biological, radiological, or nuclear hazard or incident (JP 3-11). CBRN survivability includes all aspects of protecting personnel, weapons, and supplies from such an incident while still performing required missions. The AV was not considered to be CBRN survivable unless it was equipped with extensive monitoring, hardening, and air filtering technologies that would go beyond the scope of this project.

8.2.4 Chemical, biological, radiological, nuclear, and explosive (CBRNE) preparedness

CBRNE preparedness includes having plans, policies, procedures, training, and equipment necessary to effectively respond to CBRNE incidents. No CBRNE preparedness adjustments resulted from the AV project. Future potential to equip AVs with CBRNE detection capability that would use the AV as a mobile detection platform for early warning was noted.

8.2.5 Continuity of operations (COOP)

COOP is defined as uninterrupted performance; or the degree or state of being continuous in the conduct of functions, tasks, or duties necessary to accomplish a military action or mission (JP 3-0, ADRP 4.0). The AV was not incorporated into the installation COOP plan due to its limited duration. JBM-HH would not integrate transportation such as the AV into the COOP until completion of a 9-month minimum duration of service or activity, and policy or procedure integration into the installation's fleet management.

8.2.6 Cybersecurity

Cybersecurity is defined as actions taken within protected cyberspace to prevent unauthorized access to, exploitation of, or damage to computers, electronic communications systems, and other information technology, including platform information technology, as well as the information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation (JP 3-12). Cybersecurity was an initial high level of concern for the project as a key component of the contract was to provide the AV data to ERDC. However, due to the insulated nature of the AV operation with no dynamic transmission or reception of data while operating on JBM-HH, this concern was minimal. The hard drive located in the interior roof of the AV was taken to an off-installation location periodically and the sensor data was uploaded via a high-speed connection to the ERDC government cloud storage site. Data integrity and authentication before upload into the ERDC government cloud storage relied on the contractor. It is anticipated that future AV pilots will include 5G networks with both edge and cloud computing and integrated data analytics. These advanced and integrated systems that inform real-time decision-making will have additional cybersecurity concerns that require a more robust cyber vulnerability assessment to protect data and an intentional data architecture. For hardware security, a Security Technical Implementation Guide for AVs on installations is needed to specify prudent actions and hardening options. For software and data, a security classification guide is needed to specify appropriate levels of data classification and the associated data storage, transmission, protection, sharing, and handling responsibilities for data that is collected by AVs. ERDC's ongoing effort to develop these guides is using a process that is informed by past and current AV pilots.

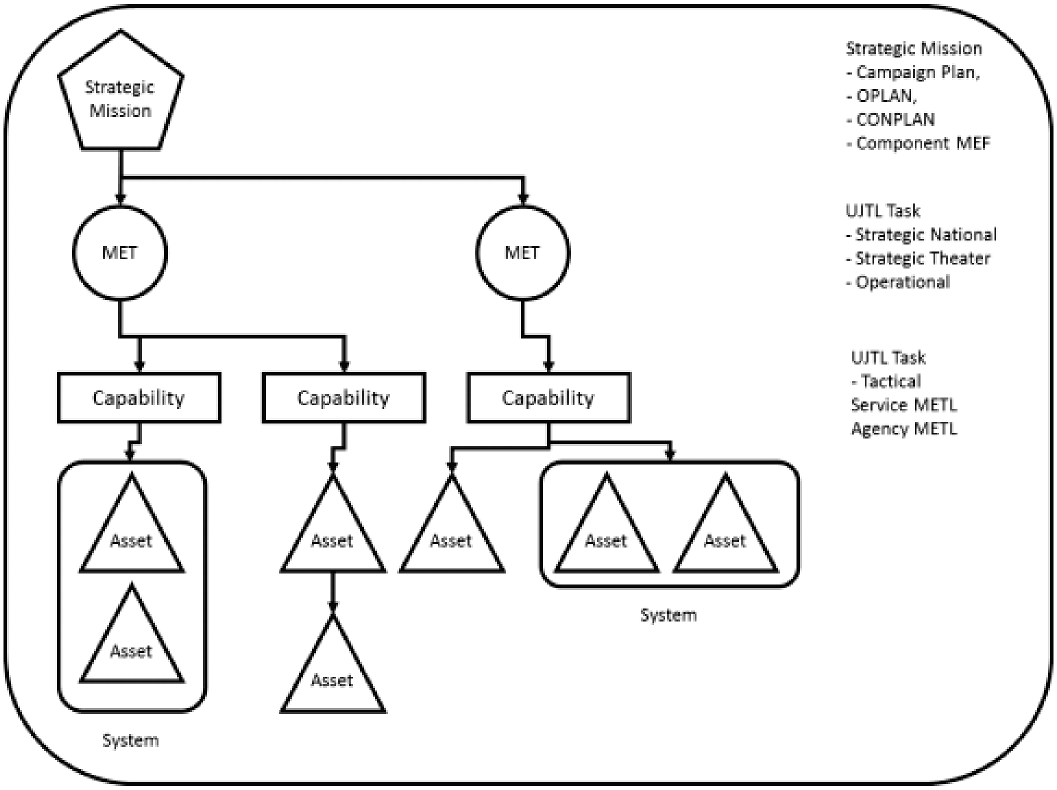
8.2.7 Defense Critical Infrastructure (DCI)

DCI is defined as Department of Defense and non-Department of Defense networked assets and facilities essential to project, support, and sustain military forces and operations worldwide (JP 3-27). Key references for the DCI program include:

- Presidential Policy Directive (PPD) –21 Critical Infrastructure Security and Resilience (White House 2013).
- National Infrastructure Protection Plan (DHS 2013).
- Department of Defense Directive 3020.40, *Mission Assurance* (DoD 2016).
- Department of Defense Instruction 3020.45, *Mission Assurance Construct* (DoD 2018).
- DCI LOE Security Classification Guide (cf. DoD 2018).
- Army Regulation (AR) 525-2, Army Protection Program (HQDA 2014).
- AR 525-26, *Critical Infrastructure Risk Management (Army)* (HQDA 2004).
- HQDA EXORD 070-18 FY 2018 Critical Infrastructure Risk Management (CIRM) FY17 All Hazards Risk Assessments (March 18).

DCI did not impact, nor was impacted by the AV project. Figure 54, "MA Identification Process Relationships," displays the process of how DCI assets are identified at the strategic, operational, and tactical levels. As AVs on installations become more prevalent, appropriate echelons should incorporate the system and network requirements outlined into their own MA process.

Figure 54. Mission assurance identification process relationships.



Source: DoDD 3020.40, Nov 2016

8.2.8 Defense Security Enterprise (DSE)

DSE is defined as the organizations, infrastructure, and measures (to include policies, processes, procedures, and products) in place to safeguard DoD personnel, information, operations, resources, technologies, and facilities against harm, loss, or hostile acts and influences. This system of systems comprises personnel, physical, industrial, information, and operations security, as well as SAP security policy, critical program information protection policy, and security training. It addresses, as part of information security, classified information, including sensitive compartmented information, and controlled unclassified information. It aligns with counterintelligence, information assurance, foreign disclosure, security cooperation, technology transfer, export control, cybersecurity, nuclear physical security, chemical and biological agent security, AT, force protection, and mission assurance policy and is informed by other security related efforts (DoDD 5200.43). The comprehensive DSE policy and framework provides for the alignment, synchronization, support, and integration of related security functions.

DSE is at the department and agency levels and did not apply directly to the AV project at JBM-HH. It was noted that AV sensors can feed into advanced data analytics for installation operations centers to increase situational awareness for both short term base operations and long-term infrastructure management and decision-making processes that impact the DSE. Any future program executive office related to AVs on military installations should integrate DSE considerations.

8.2.9 Emergency management

Emergency management is a subset of incident management and concerns the coordination and integration of activities that are necessary to build, sustain, and improve the capability to prepare for, protect against, respond, recover from, or mitigate threatened or actual natural disaster, acts of terrorism, or other manmade disasters (ADRP 1-02). MA area #2 related to AT addresses many of the concerns in this area. JBM-HH Emergency Services personnel did some limited training on the AV. Additionally, the AV contractor provided an overview of the vehicle, onboard hazards, related systems, and recommended emergency, fire, and evacuation procedures.

8.2.10 Energy resilience

Energy resilience is defined as the ability to prepare for and recover from energy disruptions that impact mission assurance on military installations (DoDI 4070.11). No installation=wide power disruptions occurred during the project. Future energy resilience considerations include integrating electric-powered AVs into the installation microgrid and updating Installation Energy and Water Plans (IEWPs) to include the load demand (for charging AVs) and potential mobile energy sources of AVs to power critical systems.

8.2.11 Fire prevention and protection

Fire prevention and protection is protecting the U.S. homeland and critical bases of operation through preventive risk management, education, emergency response, and risk communication as they relate to fire (DoDI 6055.17). No further consideration for Fire Prevention and Protection beyond what is under MA area #9, Emergency Management, were considered for the AV project.

8.2.12 Force health protection

Force health protection is defined as all measures taken by commanders, supervisors, individual Service members, and the MHS to promote, protect, improve, conserve, and restore the mental and physical wellbeing of Service members across the range of military activities and operations. These measures enable the fielding of a healthy and fit force, prevention of injuries and illness and protection of the force from health hazards, and provision of medical and rehabilitative care to those who become sick or injured anywhere in the world (DoDD 6055.17).

One of the AV fixed route stop locations was at the installation medical clinic (Andrew Raider Clinic) to enhance the provision of medical and rehabilitative care through transportation options. An injured person who stated she had a broken leg was observed riding the AV along with one of her children. She was not in a wheel chair and was able to climb aboard the AV without the use of a ramp or any assistive devices or aid by the safety steward. ADA accessibility was a key concern for the regional transportation planner and the next version of the AV is planned to have a fully deployable wheel chair ramp for accommodation. The installation noted that finding ADA accessible vehicles can be a challenge and may be a niche transportation need that AVs can provide in the future. No accidents with property damage or personal injuries occurred during the AV pilot. Thus, the AV was perceived to improve overall force health protection.

8.2.13 Insider threat

An insider threat is defined as a person who uses their authorized access to Department of Defense facilities, systems, equipment, information or infrastructure to damage, disrupt operations, commit espionage on behalf of a foreign intelligence entity or support international terrorist organizations (JP 1-02, ADRP 2-0). A primary concern for insider threats is related to the safety stewards who were granted access to the installation and had physical and operational control over the AV and access to facilities for vehicle charging, maintenance, and a work station for data upload. Safety stewards went through a screening process as is done for other contractors gaining access to the installation. The contractor used a veterans-preference in hiring and selecting the fleet manager and safety stewards that worked on JBM-HH. Traceability for data access, storage, and tampering for the AV data is desired but was not available to the project team until the data were ultimately stored in the ERDC government cloud storage site.

Recommendations for future projects to mitigate insider threat include requiring the contracted fleet manager to acquire a DoD CAC, conducting interviews on the installation that would prove accessibility before hiring or training on the technology, allowing adequate time for background checks and training, and sending reports or data in an encrypted format.

8.2.14 Law enforcement

Law enforcement is defined as policing and performing associated law enforcement activities to control and protect populations and resources to facilitate the existence of a lawful and orderly environment (ADRP 1-02). Law enforcement impact was minimal as no incident responses related to the AV operation occurred during the project. Law enforcement efforts focused on traffic rules and speed enforcement along the route, but no tickets were issued that were directly attributed to the AV project. Some aggressive driver behavior, passing, and cutting through parking areas to avoid the AV apparently due to its slower speed were observed. Other observers noted that drivers appeared to learn the conservative behavior of the AV, and then take advantage by cutting off the AV or going ahead of turn at intersections knowing the AV would yield.

8.2.15 Munitions operations risk management

Munitions operations and risk management implements the Explosives Safety and Munitions Risk Management (ESMRM) Policy of DoDD 6055.09E. The policy priorities are to protect people and property from the unintentional, potentially-damaging effects of DoD military munitions; expose only the minimum number of people for the minimum time to the minimum amount of military munitions required to safely and effectively execute the mission; provide for the explosives and chemical agent safety of DoD military munitions throughout the munition's life cycle as a DoD military munition and without regard to its location; and require DoD components to implement and maintain an effective explosives safety management program. Munitions operations were not impacted by the AV project on JBM-HH. Future consideration of AVs to enhance the safety of munitions operations by minimizing exposure of people to munitions may become a compelling use-case to develop.

8.2.16 Operational energy

Operational energy is defined as the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by power systems, generators, logistics assets, and weapons platforms employed by military forces during training and in the field. Operational energy does not include the energy consumed by facilities on permanent DoD installations, with the exception of installations or missions supporting military operations. Operational energy does not include the fuel consumed by non-tactical vehicles (DoD Directive 5134.15). No further impacts other than those already documented in MA#10, energy resilience, were noted specific to operational energy as related to the project.

8.2.17 Readiness reporting

Readiness is defined as the ability of military forces to fight and meet the demands of assigned missions (JP 1). The Defense Readiness Reporting System (DRRS), as outlined in DoDD 7730.65, provides a means to manage and report the readiness of the DoD and its subordinate components to execute the National Military Strategy (NMS) to both the President and Congress, and to identify high and significant risks. The AV project did not directly impact readiness reporting for JBM-HH. However, it is anticipated that future AV integration to installations will have impacts on installation status reporting within the DRRS framework related to areas of infrastructure, services, and mission capabilities.

8.3 Way forward

The program integration LOE is an ongoing effort that explores how the application of AVs on installations impacts mission readiness and mission assurance in their function as strategic staging areas under MDO and in the joint/interagency environment. AVs demonstrated a potential to impact each of the MAs if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DoD and varied mission sets. AV technologies present opportunities to improve mission readiness/mission assurance and inform decision-makers at installations, as well as leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work.

The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the NVRC pending funds availability. A "way forward" matrix is proposed (Table 5) that identifies strategic future smart bases and AV pilot locations with known interest in future development, along with their unique geography/climates, academic partners, and joint force mission sets for a proposed structured R&D framework that builds on this foundational project. An adequate sample of field sites and AV technologies is required before the lessons learned from this single case study can be integrated into formalized installation policy or regulation.

Table 5. Proposed "Way Forward" to investigate AV and smart base technologies.

Location	Geography / Climate	Academic Partner	Mission Set
Joint Base Myer-Henderson Hall & Pentagon, Virginia	Urban environment, Atlantic coast, four seasons	George Mason University and Virginia Tech	Washington DC headquarters support
Ft Carson, Colorado	Mountains and high plains, high altitudes, four seasons	University of Colorado - Boulder	Combat Deployment: 4th Infantry Division (5 brigades)
Miramar Marine Corps Air Station, Naval Base San Diego	Desert and low mountains, Southwest temperate and Pacific coast	University of California – San Diego	Combat Deployment: Marine Air Wing National Force: Shipyard and Naval Support Group
Ft Leonard Wood, Missouri	Woodland, Midwest four seasons	Missouri University of Science and Technology	Institutional Training: Basic, Driver, Convoy, Engineer
Redstone Arsenal, Alabama	South-east region, low altitude, high heat and humidity	University of Alabama	Sustainment: Army Materiel Command
Ft Benning, Georgia	South-east region, varied terrain, high heat and humidity	Georgia Tech University	Combat Deployment and Institutional Training
Rantoul and Champaign, IL	Midwest plains, four seasons, intermodal transportation	University of Illinois	Smart Installation and Autonomy Research

8.4 Results and recommendations

The program integration LOE that examined the elements of mission assurance and explored broader implications to the joint and interagency environment produced the following results and recommendations.

- Mission assurance impacts were examined through the 17 mission assurance areas that DoD has used to operationalize resilience. AVs demonstrated a potential to impact each of these areas if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DoD and varied mission sets.
- AV technologies present opportunities to improve mission readiness/mission assurance and inform decision-makers at installations, as well as to leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work.
- ERDC is collaborating with current Army Futures Command-CCDC Ground Vehicle Systems Center robotics and Army Futures Command (AFC) Sustainment efforts. Findings of this project are being fully integrated with ERDC Robotics Engineer Operations for combat engineering tasks and the Fort Leonard Wood Contingency Base Technology Engineering Center AV test-bed.
- Joint integration of the project is demonstrated by follow-on research of an AV installation deployment that is planned for Marine Corps Air Station Miramar beginning in 2020, with potential to expand to Naval Base San Diego. Consultation with Joint Base Andrews is ongoing for Air Force AV deployment contract development and energy analysis.
- The results from this project were shared at the kickoff meeting for the Fort Carson, Colorado AV deployment and research project for ERDC that builds on JBM-HH. The policy and planning implications captured are shaping that effort and will be reported to Congress to inform development of military installation guidelines for smart installations and AV technology in the future.
- Multiple academic institution partnerships have resulted from this project. ERDC has completed an Educational Partnership Agreement and Cooperative Research and Development Agreement with George Mason University anticipating JBM-HH Phase 2, and several other university agreements are pending for related projects.

- The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the NVRC, pending funds availability.
- This research built on previous ARL and TARDEC ARIBO program for wounded warriors at Fort Bragg from 2015-2018.
- A "way forward" matrix is proposed that identifies strategic future smart bases and AV pilot locations, geography/climates, academic partners, and joint force mission sets for a structured R&D framework that builds on this foundational project.

9 Conclusions

9.1 Project summary

This project was a joint collaboration of the Army, Marine Corps, and industry elements to plan, develop, demonstrate, and employ AV technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90-day pilot study from 19 June to 27 September 2019 to evaluate the commercially-available Olli AV and to assess the potential to enhance mission assurance and readiness, reduce base operating costs, improve safety and quality of life for military Service members and their families, and provide transportation services more efficiently and effectively. Successful performance on JBM-HH during this time frame offers expansion into the surrounding community through cooperative efforts with state and local governments of the NVRC. This project advances past research and will enhance installation understanding of the process, infrastructure, human factors, and data systems involved in AV deployments to leverage it for internal optimization and protect it from external exploitation.

9.2 Impact

- ***People:*** Over 379 Service members, families, and guests at JBM-HH had the opportunity to ride the Olli AV, with many more interactions occurring while using the base transportation system. Over 107 surveys were gathered for feedback on their experiences during the 90-day deployment.
- ***Product:*** AVs provided shuttle service along the main routes of JBM-HH in a circular pattern from Wright Gate to South Gate during a 2-hour lunch period on weekdays over 7 weeks and for special events throughout the 90-day pilot. Data from AV sensors including LiDAR, radar, cameras, and vehicle telemetry of 92,092 files at 6 terabytes were transferred to a secure Federal government cloud storage for future data mining and analysis. Vehicle control unit and telemetry data were evaluated as part of an energy consumption study with a comparative analysis of the battery management system data, the vehicle operational limits, and the existing GSA fleet diesel powered vehicle used as a shuttle.
- ***Policy:*** The successful deployment of AV technology on JBM-HH proved viability within constraints and sets the stage for Phases 2 and 3 within the surrounding community and the Northern Virginia Region to further answer remaining research questions. The current

immaturity of fully AV technology limits wide deployment on military installations. Lessons learned are shaping the current planning and development of a Fort Carson, Colorado AV deployment and research projects for ERDC. The policy and planning implications captured will be published with other AV case studies and will inform development of military installation guidelines for AV technology in the future.

- ***Partnership***: The JBM-HH pilot enhanced Federal, state, local, academic, and commercial sector cooperation and learning about AVs through weekly stakeholder synchronization meetings during the 90-day pilot, an educational partnership agreement between ERDC and George Mason University, over 25 special AV events, and open invitations for government agencies and the public to experience the JBM-HH pilot. Partnering to demonstrate AV viability at JBM-HH while conducting research to quantify mission readiness impacts, transportation system requirements and effects, and cost savings of the technology introduced new relationships with several universities, USDOT, DHS, AASHTO, Cooperative Automated Transportation Coalition, and various industry AV manufacturers and providers.

9.3 Key milestones reached

- 4 April 2019: JBM-HH announced to be National Capital Region Local Motors Olli Fleet Challenge location for AV pilot.
- 16 June 2019: The Federal acquisition process completed with award of sole-source, firm fixed price contract to Local Motors for data transfer and process reporting during Phase 1. Two additional options included in the contract will continue data transfer and process reporting during Phase 2 and 3.
- 19 June 2019: JBM-HH Launch Event and Olli begins Phase 1a operations for invitational events. Launch event speakers include Cathy McGhee, Director of Research and Innovation at the Office of the Virginia Secretary of Transportation; Jay Rogers, CEO and co-founder of Local Motors; along with Army and Marine Corps leadership.
- 12 August 2019: Phase 1a completed with total of 16 events and 171 riders on Olli for 0.9-mile demonstration route. Phase 1b operations begin along 4.4-mile fixed route from Wright Gate to South Gate of JBM-HH with 14 stops and two Olli AVs from 1100-1300 hrs daily.
- 18 September 2019: Conducted afternoon roundtable at JBM-HH of all stakeholders to document project outcomes related to mission assurance and mission readiness, safety and quality of life, and transportation services and costs.

- 27 September 2019: Phase 1b completed with total of 7 weeks (35 days) of fixed route transportation service with over 450 miles traveled, 208 riders, 12 events, and 137 safety steward takeovers conducted.

9.4 Summary of results and recommendations by LOE

9.4.1 Planning and policy

- There were no safety incidences of personal injury for the duration of the pilot. Olli errs on side of safety and comes to a full stop before any potential issues arise. However, this behavior was disruptive to the existing traffic system, perceived by some as overly conservative, and resulted in some drivers risking illegal maneuvers to avoid the AV as noted in "human factors." This identifies a trade-off between risk and value, or risk and efficiency that requires more AV experience and technology development to determine policy.
- Historically, the Federal government has approved commercial vehicle types to operate on public roads at the level of the original equipment manufacturer, while state governments have approved individual drivers as operators and licensed specific vehicles. AVs combine these into a single entity such that issues related to design, crashworthiness, licensing, and insurance are currently ill-defined and unstandardized. Working with strategic partnerships like AASHTO, USDOT, states and regional partners near installations on other pilots will inform this ongoing process so military installations can integrate with the latest information, regulations, and priorities.
- A long-term transportation plan and study is needed to "right size" AV fleet and supporting infrastructure to meet both system goals and user objectives. This process was compressed into a very short time period and done in reverse based on available AV fleet and time period for the pilot study, but utilization of the transportation service was suboptimal.
- Review current installation planning documents and policies demonstrates a gap in addressing AVs. Developing a framework and guidance for future planning practice related to vehicle and fleet management, work force development, data sharing, security, legal, infrastructure and rights of way, and installation development considerations will require additional AV pilots at more installations.
- Engage with first responders and public safety officials in the planning process. To ensure public safety, first responders and public safety officials (including police, fire, emergency medical services, and towing) need to have ways to interact with AV during emergencies. Responders

and safety officials will need information and training to safely interact with AVs—including how to disable the vehicle, how to react if it is on fire, and how to move the vehicle.

- Relationships and roles within the stakeholder group need to be clear. Participants ask things of others that they think are simple, but in practice may be easier said than done, or conversely, some hesitate to ask for fear of generating an overburdening request.
- Appropriate messaging, public engagement and education activities to promote awareness, understanding, and acceptance of AVs, along with an engaged champion for the effort contributes greatly to the success. Ongoing communication to AV users and potential users with up-to-date information is also key to education and engagement activities.
- Workforce development impacted the project as key positions of fleet manager and safety stewards were hired during the 90-day pilot. Planning for workforce hiring, training, and integration with an ongoing AV service will help in communication and delivery of services on time.

9.4.2 Infrastructure and Operations

- The existing road and roadside infrastructure was adequate for AV deployment with no major investments required to improve or change current system at JBM-HH before the pilot. All roads were two-lane traffic and all intersections were stop sign controlled. An RDK antenna was provided by the contractor and temporarily installed on top of a building during the deployment to ensure GPS accuracy of the AV during operation.
- Mapping and establishment of the base route took 3 weeks of AV onsite preparation, and additional routes were not added later in the project due to the cost and resources required to bring back the mapping team, while the installation originally planned for only days to accomplish this task. Consider if mapping can be done in advance or develop standards and specifications for installation to deliver this to AV providers.
- Traffic operations were sometimes impacted by the AV maximum speed of 12 mph with queues forming behind the AV. Numerous shuttle stop locations and two-lane roads with curb and gutter on each side restricted pull-out locations for the AV during fixed route operation restricting ability of other vehicles to pass the AV during loading/unloading of passengers. Planned shuttle stops would preferably allow the AV to pull over and stop for loading/unloading without impacting normal traffic operations.
- Sufficient quantity, type, and location of electric-powered vehicle charging stations is critical for infrastructure and fleet management planning. One compatible and high-speed charger was available for the

two Olli AVs on JBM-HH and this was purchased by the installation before the project and located in the AV storage garage.

- Operation of the AV was constrained by inclement weather and darkness. Rain caused stopping of operations due to safety concerns over sensor reliability and wheel slippage. Heating and air-conditioning caused increased battery usage. Summertime operation was conducted only in daylight hours, but cold weather and darkness would be expected to increase battery usage for heating and lighting.
- Operation of AV was constrained by environmental conditions. Examples included “unlearned” scenarios of road construction, parked buses, or incidents requiring off-tracking from geo-fenced and mapped areas. Steeper grade of 7% from Wright Gate to Stop #3 increased battery usage, slowed the AV, and challenged its climbing and maneuver capability. Navigating over steel spike security strips employed at both Wright Gate and South Gate resulted in damage to one AV rendering it inoperable for 1 week. Typical ground clearance of the Olli with passengers was 4 in. and for military installation applications should be higher and similar to standard highway automobiles.
- The AV operations team required designated work space for team meetings, vehicle and tool storage and maintenance, data download, and standard office functions. The installation maintenance bay provided to the AV team was mostly adequate for the pilot, except for data transmission that occurred offsite. Ideally, high-speed internet or 5G access along with a more robust office setting sized for the AV fleet and team would be incorporated into the AV parking and maintenance location.

9.4.3 Data Architecture and Cybersecurity

- A standardized mechanism for indexing data from various sources of AV technology systems is needed to establish a solid data architecture and to allow common data queries and effective application of post-processing methods and data analysis.
- Data security for project was high; however, this was primarily due to the self-containment of the AV system on the vehicle with no reliance on any external network access. Although this was secure, it also resulted in a lack of real-time data transfer. Data transfer into secure government cloud storage occurred manually through periodic offloading via portable hard drives and overnight uploading with secure offsite internet connections. Edge computing and real-time data were limited in this configuration. This highlights the trade-off between risk and value.

- Reliability of the AV was uncertain based on instances of hard reboot requirements for the onboard system, which resulted in AV inoperability. Apparent fragility of the technology stack and integration with the AV sensor package demonstrated a need for continued development of more robust and resilient data processing and technology systems.
- Sharing data requires a specific intergovernmental agreement or memorandum of understanding that entails a complex, extensive legal review. Data sensitivity, privacy, ownership, stewardship, reporting, restrictions, and disclosure are all important considerations.
- The AV fleet manager or a key person on the AV delivery team needs to have CAC-access to the DoD network if they will interact with a DoD-approved system. This was not required during this pilot but was noted as important for future considerations and data sharing.
- Developing and documenting physical, operational, communications, and cybersecurity assessment protocols will require further research studies and use-case applications with multiple AV technologies at varied installation locations with diverse missions. Both the data environment and the applications require an integrated security approach that is currently ill-defined in the 4G and 5G networks.

9.4.4 Data Analytics

- AV sensors and technology are deployed to prioritize and optimize data gathering and decision-making for vehicle maneuver and navigation. Most of the AI and data integration software for this purpose are proprietary products.
- Raw sensor data from AV LiDAR and cameras were processed into video feeds for visual assessments and review. This process, which requires large data storage capacity for HD video files, was not done in real-time. Video analysis of safety steward interventions proved challenging as searching accurate time stamps for interventions and viewing various sensor data to fully understand context was extremely time consuming.
- ERDC developed a framework to count passengers onboard the AV with acceptable reliability using AI and Cognitive Services.
- ERDC attempted to use Cognitive Services to develop an AI framework to determine queue length of vehicles behind the AV; however, the external camera location on the rear of the vehicle was too low to do so with acceptable reliability. Further research is needed to determine if a camera on top of the AV or remote sensing is feasible for real-time queue detection.

- Data mining review by time/location for incidents involving safety steward takeover of AV are possible. Integration of GPS or other location data is essential for real-time data analytics.
- Edge computing use-cases that are most beneficial to installations for real-time analytics should drive future investment in AI and supplementary sensor integration into current AV technology.

9.4.5 Energy and Economy

- Battery drainage of the AV was higher than expected during operations and is a constraint. While the average range for the AV specifications was 20 miles for maximum load and 35 miles nominal, the realized range was on the order of 16 to 19 miles, or approximately 55% of nominal. A single fast AV charging station was installed on the military installation and was used to alternatively charge the two AVs.
- The Olli has a maximum battery capacity of 18.5 kWh, but the fleet manager's protocol was to ensure that the charge stayed above 20% of battery; thus if the vehicle did drop to 25%, the safety steward would immediately drive the vehicle back to the charging station location to ensure that the vehicle did not lose power in a manner or place that was unsafe. This business practice should be considered in route selection, charger location, and overall planning.
- Cost of operational energy for the AV ranged from $0.05 to $0.08/mile driven; and $0.26 to $0.30/hr of operation during fixed route transportation service based on the current price at JBM-HH of $0.07/kWh. Efficiency of AV operation ranged from 0.69 kWh/mile to 1.14 kWh/mile. Energy usage and consumption for AVs varies with context of operations to include topography, temperature, vehicle and cargo weight, acceleration/deceleration zones, and additional battery loads such as heating/air-conditioning, and frequency of opening and closing of doors.
- A 10% loss in energy between the charging station power required and the battery charge received was observed in the data. This is a reasonable planning factor for converting operational energy demand to supplied energy and cost.
- Developing language for competitively bid AV mobility service should consider energy requirements and performance and whether government or contractor is responsible for each.
- The datasets from the AV are disparate and difficult to integrate for evaluation of energy use, miles driven, hours of operation, vehicle status, and location in a time sequence that allows detailed econometric analysis. Future data indexing and collection should consider this in

the data architecture design stage for determining data collection frequency, latency, and integration goals of the project.
- Understanding the full range of data collected by the vehicle control unit and battery management system is useful in developing use-cases for AV sensor data and second-order benefits of AV deployments such as condition assessments, facility monitoring, or emergency operations notifications.

9.4.6 Human Factors

- A 21-question survey was approved through IRB process for human subject's research with 154 surveys used for analysis of trust in autonomy, basic demographics, and perception of safety. Results show that AVs provide a perceived value to the installation and are considered intelligent, but that subjects' responses regarding comfort and trust were mixed. Riding the AV tended to increase trust in the vehicle.
- It is recommended to determine transportation goals, user origin/destination, and mobility patterns before an extended AV implementation. Overall ridership was much lower than expected, which may be attributed to limited duration and extent of deployment, lack of advance marketing or advertising, and challenge in changing human habits and behavior. After posting flyers with operational times and locations in more public spaces, there was an increase in ridership.
- Survey results indicate that riders and non-riders want more transportation options on JBM-HH but achieving the "first and last mile" demands of users is a challenge. A better outreach mechanism is needed to inform people about the AV and its capabilities. It is recommended to extend the transportation service to transit hubs and to expand advertising beyond traditional public affairs print media to include social media, direct messaging through chain of command, and marketing to key audiences.
- Field observation determined low ridership for three primary reasons: (1) Some people wanted to know when and where Olli was operating and did not have that information; (2) Some people who had not ridden the vehicle did not think it was safe and did not realize the person onboard was a safety steward who could intervene if needed; (3) Others did not realize the Olli was available for rides after the mapping period and did not know it was free of charge as most transportation in the DC area has an associated cost.
- Most riders thought Olli was safe and added value to the installation. However, the use of safety stewards adds complexity to risks and

riders' safety perceptions. The project survey data did not detect before and after perceptions of the safety of the AV, which highlights the opportunity for future research related to safety and how trust is gained or lost through the use of technology.
- The social nature of transportation adds complexity to AV and human interaction. It will take time to build trust of an AV, and to overcome the problem of discourteous behavior. Safety is impacted when nearby drivers break the law, e.g., cross solid yellow lines, tailgate, pass illegally, etc.

9.4.7 Program Integration

- Mission assurance impacts were examined through the 17 mission assurance areas that DoD has used to operationalize resilience. AVs demonstrated a potential to impact each of these areas if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DoD and varied mission sets.
- AV technologies present opportunities to improve mission readiness/mission assurance, to inform decision-makers at installations, and to leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work.
- ERDC is collaborating with current Army Futures Command-CCDC Ground Vehicle Systems Center robotics and AFC Sustainment efforts. Findings of this project are being fully integrated with ERDC Robotics Engineer Operations for combat engineering tasks and Fort Leonard Wood Contingency Base Technology Engineering Center AV test-bed.
- Joint integration of the project is demonstrated by a follow-on research of an AV installation deployment that is planned for Marine Corps Air Station Miramar beginning in 2020, with potential to expand to Naval Base San Diego. Consultation with Joint Base Andrews is ongoing for Air Force AV deployment contract development and energy analysis.
- The results from this project were shared at the kickoff meeting for the Fort Carson, Colorado AV deployment and research project for ERDC that builds on JBM-HH. The policy and planning implications captured are shaping that effort and will be reported to Congress to inform development of military installation guidelines for smart installations and AV technology in the future.
- Multiple academic institution partnerships have resulted from this project. ERDC has completed an Educational Partnership Agreement and

Cooperative Research and Development Agreement with George Mason University in anticipation of JBM-HH Phase 2, and several other university agreements are pending for related projects.

- The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the NVRC pending funds availability.
- This research built on previous Army Research Lab and TARDEC ARIBO program for wounded warriors at Fort Bragg from 2015-2018.
- A “way forward” matrix (Table 6) is proposed that identifies strategic future smart bases and AV pilot locations, geography/climates, academic partners, and joint force mission sets for a structured R&D framework that builds on this foundational project.

Table 6. “Way forward” matrix.

Way Forward

Location	Geography / Climate	Academic Partner	Mission Set
Joint Base Myer-Henderson Hall & Pentagon, Virginia	Urban environment, Atlantic coast, four seasons	George Mason University and Virginia Tech	Washington DC headquarters support
Ft Carson, Colorado	Mountains and high plains, high altitudes, four seasons	University of Colorado - Boulder	Combat Deployment: 4th Infantry Division (5 brigades)
Miramar Marine Corps Air Station, Naval Base San Diego	Desert and low mountains, Southwest temperate and Pacific coast	University of California – San Diego	Combat Deployment: Marine Air Wing National Force: Shipyard and Naval Support Group
Ft Leonard Wood, Missouri	Woodland, Midwest four seasons	Missouri University of Science and Technology	Institutional Training: Basic, Driver, Convoy, Engineer
Redstone Arsenal, Alabama	South-east region, low altitude, high heat and humidity	University of Alabama	Sustainment: Army Materiel Command
Ft Benning, Georgia	South-east region, varied terrain, high heat and humidity	Georgia Tech University	Combat Deployment and Institutional Training
Rantoul and Champaign, IL	Midwest plains, four seasons, intermodal transportation	University of Illinois	Smart Installation and Autonomy Research

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Acronyms and Abbreviations

Acronym	Definition
AAR	After-Action Review
AASHTO	American Association of State Highway and Transportation Officials
ADA	American with Disabilities Act
API	Application Program Interface
AR	Army Regulation
ARIBO	Applied Robotics for Installations and Base Operations
ARL	Army Research Laboratory
ASA IE&E	Assistant Secretary of the Army for Installations Energy and Environment
AT	Anti-Terrorism
AV	Autonomous Vehicle (or Automated Vehicle as defined by USDOT AV 4.0 guidance)
BAA	Broad Agency Announcement
CAV	Connected and Autonomous Vehicle (or Connected and Automated Vehicle)
CBRN	Chemical, Biological, Radiological, and Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosive
CCDC	Combat Capabilities Development Command
COOP	Continuity of Operations
DASA	Deputy Assistant Secretary of the Army
DCI	Defense Critical Infrastructure
DoD	Department of Defense
DPW	Department of Public Works
DSE	Defense Security Enterprise
ESMRM	Explosives Safety and Munitions Risk Management
FAST	Fixing America's Surface Transportation
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FPCON	Force Protection Condition
GIS	Graphical Interface System
HAV	Highly Automated Vehicle
JBM-HH	Joint Base Myer-Henderson Hall
LM	Local Motors
LOE	Line of Effort
MA	Mission Assurance
MCICOM	Marine Corp Installation Command
MDO	Multi-Domain Operations

Acronym	Definition
MOA	Memorandum of Agreement
NEC	Network Enterprise Center
NHTSA	National Highway Traffic Safety Administration
NIWC	Naval Information Warfare Center
NVRC	Northern Virginia Regional Commission
PAIO	Plans, Analysis, and Integration Office
RR	Robotics Research
RTK	Real-Time Kinetics
TARDEC	Tank Automotive Research Development and Engineering Center
USACE	United States Army Corps of Engineers
USDOT	United States Department of Transportation
USMA	United States Military Academy
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VDOT	Virginia Department of Transportation
PII	Personally Identifiable Information

Appendix A: AV 101

This Appendix provides a broad overview and understanding of automated vehicle systems and the associated technology. The intent is simply to provide a primer for installations, to educate and provide adequate technical background to the unfamiliar reader.

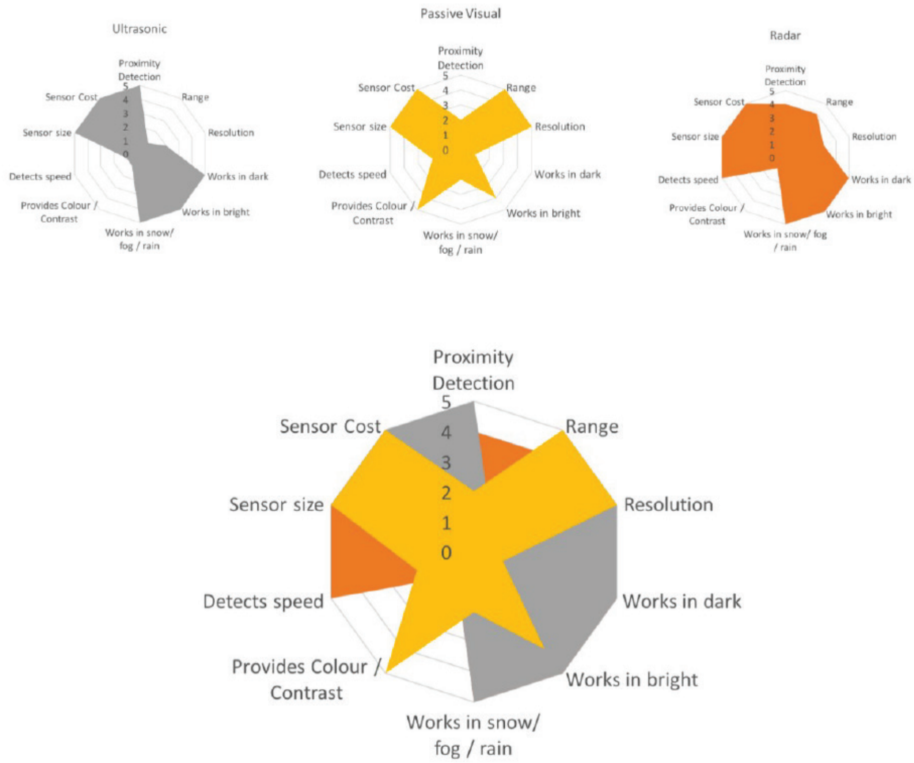
A.1 Automated vehicle technology

AV technology is an umbrella term that includes a wide variety of features and technologies that enable vehicles to take control of some or all of the major driving functions normally completed by the driver. This includes fully autonomous vehicles that no longer require a human driver to operate them, as well as a range of advanced driver assistance systems (ADAS) that enhance driver safety by taking temporary control of one or more driving functions (i.e., speed, lane position, braking, etc.). An AV must both perceive the environment and control the vehicle to varying degrees.

A fully autonomous vehicle no longer requires a human operator to drive. Instead, the vehicle relies on technologies like GPS, LiDAR, and radar to read their surroundings and make intelligent decisions about the vehicle's direction, speed, and interaction with other road users—including cyclists and pedestrians. The vehicle's combination of sensors, cameras, LiDAR, HD maps, and advanced software create a digital picture of its surroundings and make intelligent driving decisions on routing and maneuvering without any input from an operator. Figure A-4 depicts the typical AV sensor suite deployed on vehicles incorporating ultrasonic, cameras, and radar and their respective strengths.

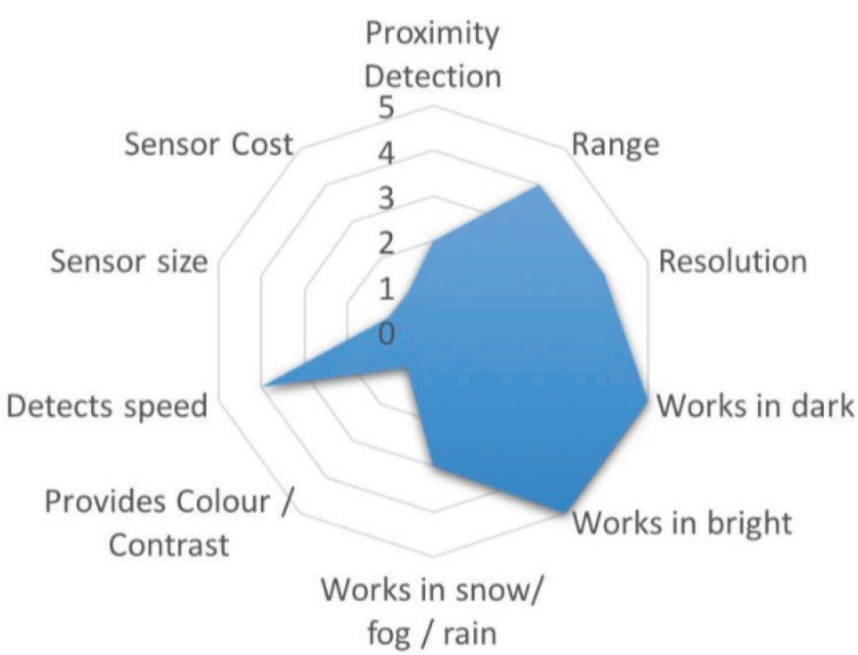
LiDAR shoots pulses of light and measures how long it takes for the light to return to the sensor to assess how far away an object is. The vehicle's central computer can then be programmed to recognize specific LiDAR returns as another car, a pedestrian, or even a stop sign. Figure A-4 demonstrates how LiDAR can substitute for ultrasonic sensors and cover a similar spectrum of capability depending on the frequency and number of light emissions and receptions.

Figure A-1. Sensor fusion of typical AV sensor suite deployed on vehicles incorporating ultrasonic, cameras, and radar.



Source: Fridman (2018).

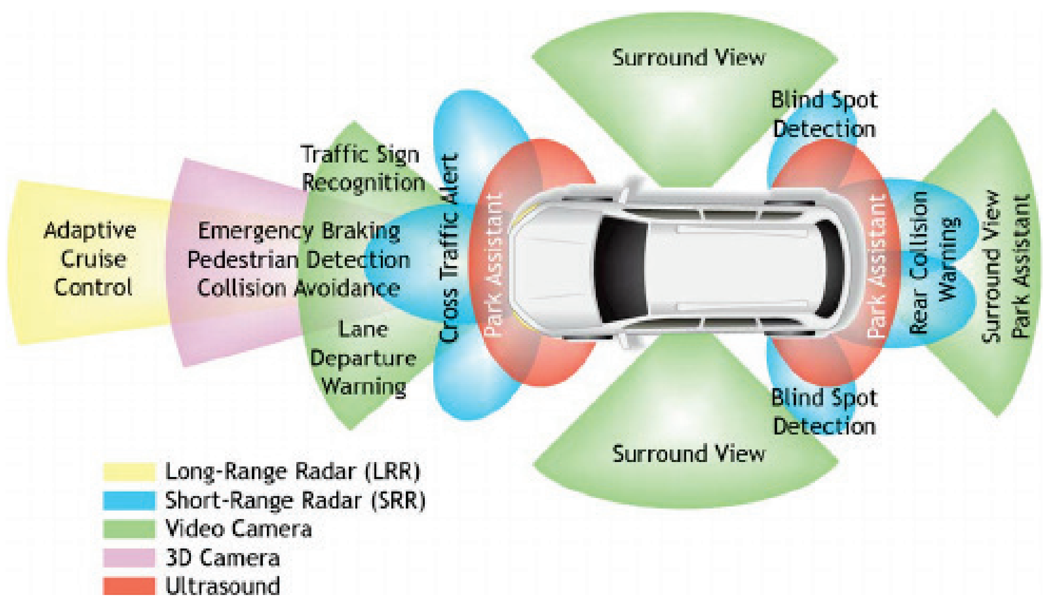
Figure A-2. LiDAR sensor adds cost but provides additional spectrum of sensor functionality and surety and was part of the Olli sensor suite.



Source: Fridman (2018).

LiDAR systems are typically supplemented by cameras or HD video and other sensors to provide redundant detection systems that detect objects that LiDAR could miss, particularly in the area immediately surrounding the vehicle. More sophisticated systems that leverage algorithms and AI add another layer of complexity by assessing how surrounding vehicles and pedestrians are moving and predicting where they will go next. In the case of a pedestrian crossing the street, advanced software can identify the object as a pedestrian, predict the pedestrian's movements, and begin slowing the vehicle before the pedestrian enters the street instead of waiting until the pedestrian is directly in the vehicle's path. With current technology limitations, whether an AV uses LiDAR or cameras or both, it is very difficult for these systems to work properly in inclement weather conditions and poor visibility. Rain and snow can refract the laser returns and cameras struggle to identify objects accurately through precipitation—functionally blinding the AV. However, using both technologies in tandem could overcome this problem as the technology continues to advance. Figure A-3 further demonstrates the integration and fusion of various technologies and links to vehicle controls.

Figure A-3. Examples of sensor integration and links to various perceptions and vehicle controls.



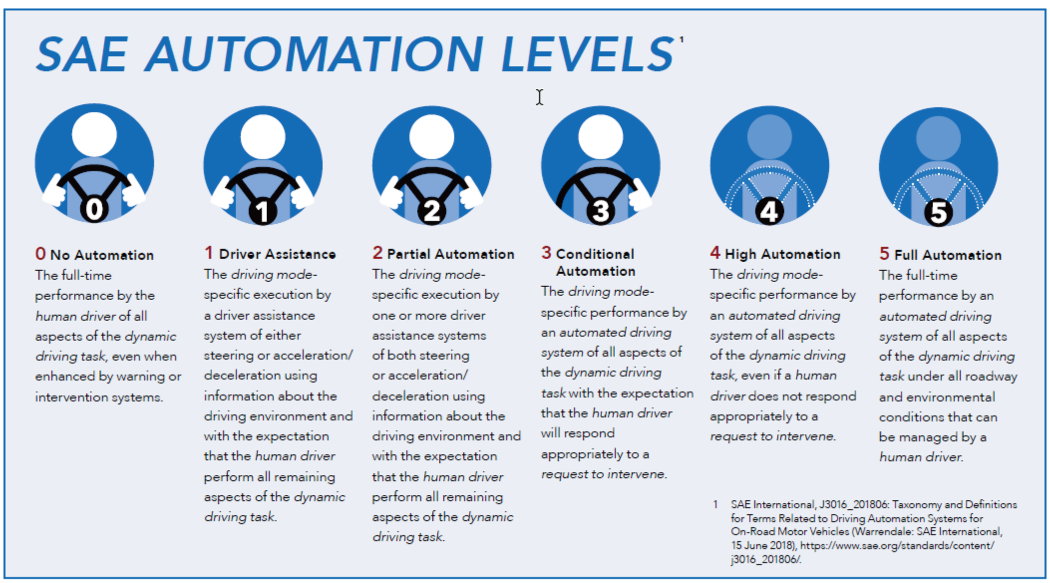
Source: "Advanced driver assistance systems trump driverless cars by stealth", Sam Francis, Robotics and Automation News, 2016.

A.2 Levels of automation

The classification used to describe the degree of automation of a vehicle is defined in standards by the International Society of Automotive Engineers (SAE). There are six levels of automation (including "Level 0," which is no automation) identified according to the approach "who does what and when"; that is, who (human driver or system) performs the operation and at what timing. Figure A-4 shows the definitions of the six levels.

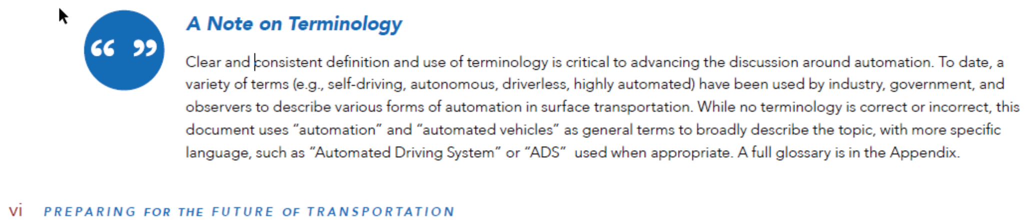
An important consideration is the confusion that results from different understandings and meanings of words related to automation levels. This report uses the term "autonomous vehicle" and AV related to the Olli, even though it mostly functioned at Level 4 automation. This use is based on background language and project history that resulted in funding of this effort. The USDOT and White House OSTP released the "AV 4.0 Guidance" during the writing of this report, therefore moving forward ERDC will attempt to align with the use of "automation" and "automated vehicles" as general terms to broadly describe the topic and will use more specific language such as "automated driving system (ADS)" when appropriate adopt the more consistent definitions reflected in Figure A-5.

Figure A-4. SAE levels of automation used for automated vehicles. The Olli AV deployed at Level 4 on JBM-HH.



Source: "Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0", USDOT/White House OSTP, 2020.

Figure A-5. This note on terminology highlights the need to bring more consistency in communicating on automated vehicle technologies and is a clarification from the January 2020 USDOT AV guidance.



A Note on Terminology

Clear and consistent definition and use of terminology is critical to advancing the discussion around automation. To date, a variety of terms (e.g., self-driving, autonomous, driverless, highly automated) have been used by industry, government, and observers to describe various forms of automation in surface transportation. While no terminology is correct or incorrect, this document uses "automation" and "automated vehicles" as general terms to broadly describe the topic, with more specific language, such as "Automated Driving System" or "ADS" used when appropriate. A full glossary is in the Appendix.

vi PREPARING FOR THE FUTURE OF TRANSPORTATION

Today's cars are generally equipped with SAE Level 1 and 2 features, commonly referred as Advance Driver Assistance Systems (ADAS), such as park assist, cruise control, adaptive front lights, and lane keeping assist. Note that these provide driver support in terms of aid, warning, and assistance rather than replace it in driving activities (automation). Few car manufacturers can offer models furnished with SAE Level 3 or higher automation functions.

With Level 1 automation, the driver remains in control of the vehicle, but the technology can assist the driver by controlling one of the vehicle's functions, either its speed or lane position. Common "cruise control" is Level 1 automation. Level 2 takes this a step further by allowing the vehicle to control two driving functions at the same time. A vehicle with Level 3 automation can take full control of the vehicle for certain parts of a trip, but the driver must be ready to take back control of the vehicle. The vehicle takes full control of all major driving functions in Level 4. Level 4 vehicles can even drive themselves for the entire trip, but they are only able to do so under specific conditions. The Olli AVs operated at JBM-HH were at a Level 4 for the specific routes that were pre-mapped into the system and used a safety steward that was able to take control if needed. Finally, Level 5 automation refers to fully autonomous vehicles that can operate without an operator in all conditions and without the capability for a human to retake control.

A.3 Connected vehicle technology

Connected Vehicles (CVs) are those equipped with advanced communication technologies that allow the exchange of information, through different communication channels, between the various elements of the transport system (i.e., vehicles, infrastructure, or pedestrians) in real-time. Based on a specific vehicle's location, information is broadcast to the vehicle so the driver (human or system) is able to make informed decisions regarding routing and maneuvering. Experts generally talk about Vehicle-to-Everything (V2X) to describe future connectivity, which includes the following:

- *Vehicle-to-Vehicle (V2V)* technologies for exchanging data between vehicles, for example, to provide and receive alerts on traffic conditions.
- *Vehicle-to-Infrastructure (V2I)* technologies for exchanging data between vehicle and infrastructure, to allow vehicle to be warned about situations of danger due to accidents and, eventually, to adapt driving to the environment, for example, when accessing areas with speed limits or any other traffic restrictions.
- *Vehicle-to-People (V2P)* technologies for exchanging data between vehicle and smartphones (or dedicated devices) to receive information about activities taking place nearby.
- *Vehicle-to-Network (V2N)* technologies for exchanging data between vehicle and the traffic control center and receiving real-time information on traffic conditions.

Simple examples of CV technology include transmitting information typically given on street signs to a heads-up display in the vehicle. For instance, a sensor embedded in the roadway could tell the vehicle what the speed limit is at all times or it could provide a warning whenever the vehicle begins traveling the wrong way down the road. More sophisticated examples could include an ambulance warning other vehicles to move out of the way or platooning, in which two or more vehicles "link" and travel together like a train.

If AVs are not connected, they require less organizational complexity, less investment in infrastructure digitalization, and provide greater cybersecurity since the possibilities of hacking are reduced. CAV combine elements of both connection and automation for more complex and sophisticated operations. The Olli AVs used at JBM-HH did not use connected vehicle technology, thus are simply referred to as AVs.

A.4 Other AV considerations

In addition to AV, CV, and CAV technology, there are several other transportation technology advancements that could complement the emergence of AVs and magnify the benefits AVs promise to provide. This includes electric vehicle technology, advanced traffic management systems, and varied AV types and applications.

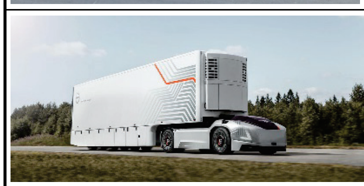
Electric vehicle technology is advancing rapidly along with automated systems. Many have speculated that because AVs will require a significantly more extensive electrical system to power the sensors and computers necessary to drive autonomously, it will be easier and more efficient to engineer AVs that are electric-powered rather than combustion-powered. Typically, Electric Vehicles (EVs) refer to vehicles that use energy from their own battery (thus excluding hybrid vehicles). Studies show that EVs bring great benefits for the environment by eliminating local emissions of polluting agents and climate altering gases. EVs are already at an advanced state of implementation. The military investment in EVs recognizes the benefit of transportable energy that integrates microgrids, EV charging stations, and vehicle or other batteries into a holistic energy system. Energy resilience and operational energy are both aspects of mission assurance that are further explored in the program integration LOE.

Advanced traffic management systems (ATMSs) (aka Intelligent Transport Systems) regard the physical mechanisms that make roads connected and cooperative (i.e., smart roads) and the intangible frameworks in which data concerning the whole transport systems are stored (i.e., digital infrastructure). Today, most ATMS use traffic data gathered from sensors and cameras embedded in the roadway infrastructure to adjust speed limits, traffic light timing, and ramp metering to improve vehicle flow and mitigate traffic congestion. CV technology could revolutionize ATMS by enabling them to be informed by data inputs from every vehicle on the road.

Yet even more transformative is the potential for ATMS to communicate with or even control the movements of vehicles across the transportation system. All data and information collected by AVs and CVs theoretically could be fed into a centralized ATMS that could provide each vehicle with optimal routing information based on real-time traffic conditions. The ATMS could safely reroute traffic away from traffic jams and safety hazards and could ensure that AVs are aware of road work, detours, and new roadway infrastructure. In this way, the combination of AV, CV, and ATMS technology could maximize the efficiency of roadway infrastructure in real time. ATMS with this level of complexity has yet to be developed and may raise important privacy issues. No ATMS were used at JBM-HH but further research to leverage ATMS on military installations provides vast opportunities.

Examples of AV types and capabilities currently in the commercial sector are useful as a point of reference for the context of the JBM-HH project, which explored two low-speed AV shuttles. The private passenger car is the focus of AV speculation, but there is a diverse range of vehicles that will be automated in different ways (Table A-1).

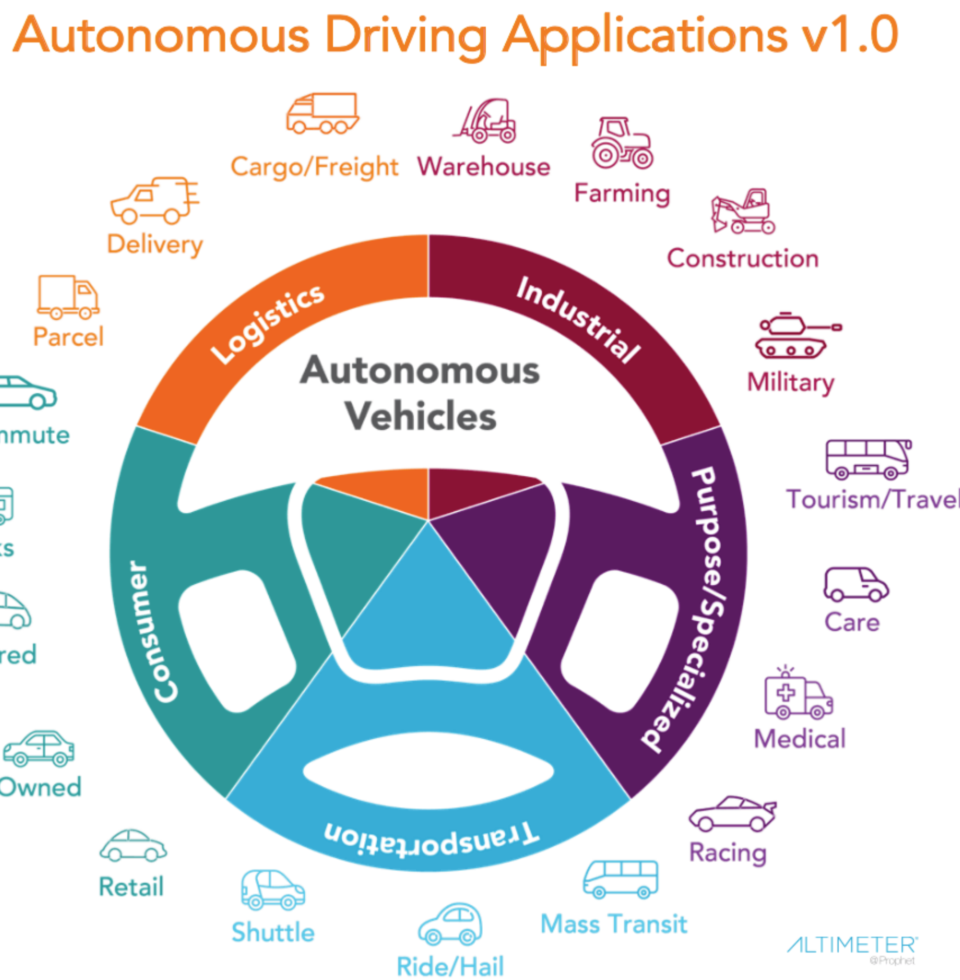
Table A-1. Currently available examples of commercial AV services and capabilities.

Example Commercial AV*	Type of AV Service	Capability	Companies or Providers
	TAXI AV taxi providing rides either as sequential private or shared simultaneously by several passengers.	4-6 passengers 25-35 mph	Uber, Lyft, Waymo
	SHUTTLE Automated minibus for carrying groups of people over short distances, usually on pre-mapped routes	8-12 passengers 10-25 mph	Navya, Local Motors, EasyMile
	DELIVERY AV cart providing last-mile light goods distribution	5-10 mph	Starship Technologies, Robby Technologies, Nuro
	COMMERCIAL HAULING Single or platooned tractor-trailer providing long-haul freight transport	44,000 lbs of cargo 55 mph	Embark, Daimler, Einride, TuSimple, Waymo, Tesla, Volvo

* Source for Pictures: Taxi: Uber self-driving car (www.uber.com); Shuttle: Local Motors Olli (www.localmotors.com); Delivery: https://roboticsandautomationnews.com/2019/01/25/top-16-autonomousdelivery-robots-ready-to-take-over-the-streets/20709/; Volvo Trucks' Vera (https://www.gearbrain.com/autonomous-truck-startup-companies-2587305809.html)

Figure A-6 shows an array of other AV applications and ideas. Potential AV applications in these areas are currently at various levels of maturity including research, development, testing, evaluation, and fielding. While the JBM-HH project focused on AVs in transportation, applications in the areas of logistics, industrial production, specialized purposes such as medical support, and consumer applications such as shared use AVs are all potential use-cases that may improve mission assurance/mission readiness, services and costs, and Soldier and family quality of life on future smart installations.

Figure A-6. Array of AV potential applications



Source: “Federal Automated Vehicles Policy”, USDOT, 2016

A.5 Commercial AVs

Table A-2 lists connected and autonomous vehicle technologies currently in the market place.

Table A-2. Comprehensive list of commercially-available connected and autonomous vehicles.

Autonomy Company & HQ Location	Robotic Research (Gaithersburg, MD)	Robotic Research (Gaithersburg, MD)	Navya (Lyon, France)	Navya (Lyon, France)	May Mobility (Ann Arbor, MI)	Optimus Ride (Boston, BA)	EasyMile (Toulouse, France)	2getthere (Utrecht, Netherlands)	Waymo (Mountain View, CA, USA)	Waymo (Mountain View, CA, USA)	GM Cruise LLC (San Francisco, CA)	Argo AI (Pittsburgh, PA)	Aptiv (Dublin, Ireland)	Tesla (Palo Al
Vehicle Company & HQ Location	Local Motors (Phoenix, AZ, USA)	Local Motors (Phoenix, AZ, USA)	Navya (Lyon, France) often partners with transport operator Keolis (Paris, France) to handle trials such as in Quebec or Las Vegas	Navya (Lyon, France)	GEM (Medina MN)	GEM (Medina MN)	Ligier (Abrest, France)	2getthere (Utrecht, Netherlands)	Chrysler (Metro Detroit, MI)	Jaguar (Coventry, UK)	General Motors (Detroit, MI)	Ford (Dearborn, MI)	BMW (Munich, Germany)	Tesla (Palo Al
Vehicle	Olli	Olli (from Maryland deployment Olli Pilot Vehicle Program)	Autonom Shuttle	Autonom Cab	Polaris GEM e6	Polaris GEM e6	EZ10	GRT	Chrysler Pacifica Hybrid	Jaguar I-PACE	Chevrolet Bolt	Ford Fusion Hybrid sedan	BMW 5 series (M5 model)	Tesla Model S
Manufacturing/Assembly Location	Local Motors Chandler Microfactory (Chandler, Arizona)	Local Motors Chandler Microfactory (Chandler, Arizona)	Navya Production Sites. (Lyon Venissieux, FR), (Saline, MI, USA)	Navya Production Sites. (Lyon Venissieux, FR), (Saline, MI, USA)	Autonomous tech incorporated onto shuttle by Magna (HQ: Aurora, Ontario, Canada) at (Troy, Michigan)		Ligier Factory (France)	Altran Engineering (Helmond, Netherlands)	Autonomous tech incorporated onto shuttle at Waymo autonomous car assembly plant (Detroit, Michigan)	Autonomous tech incorporated onto shuttle at Waymo autonomous car assembly plant (Detroit, Michigan)	Gernal Motors Orion Township assembly plant (Orion, Michigan)	New Ford Michigan plant. Scheduled to open within next 2 years.	Produced in BMW plant (Dingolfing, Germany) or outsourced to Magna Steyr plant (Graz, Austria)	Tesla Factory
Testing Location Examples (Not Exhaustive List)	Chandler, Knoxville, National Harbor, Tempe, JBMHH	Chandler, Knoxville, National Harbor, Tempe, JBMHH	Mcity MI, Europe, Las Vegas NV, Singapore, Quebec	Paris (France)	Columbus OH, Detroit MI, Grand Rapids MI, Providence RI,	Fairfield CA, Brooklyn NY, Reston VA, Boston MA, South Wemouth MA, Paradise Valley CA	Gelderland county (Netherlands), San Ramon CA, Taipai (Taiwan), Tallinn (Estonia), Singapore,	Brussels (Belgium), Bluewaters Island (UAE), Rotterdam (Netherlands), Nanyang University (Singapore), Sendai Airport (Japan)	Phoenix AZ, Atlanta GA, Detroit MI, Kirkland WA, San Francisco CA	Phoenix AZ, Atlanta GA, Detroit MI, Kirkland WA, San Francisco CA	San Francisco CA, Scottsdale AZ, Orion MI	Pittsburgh PA, Palo Alto CA, Miami FL, Washington DC, Detroit MI	Shanghai, Singapore, Boston MA, Pittsburgh PA, Las Vegas NV	N/A
Level of Automation	4 (Safety steward often still in the shuttle)	4 (Safety steward often still in the shuttle)	4 (Safety conductor oten still used)	3 or 4	4 (human safety driver still used in Michigan)	4 (human safety driver still used)	4 (designed to operate w/o an on-board attendant)	4	3 or 4 (no safety driver since Oct, 2017 in Arizona) (reports that Waymo re-added safety drivers since Nov 2018)	3 or 4 (no safety driver since Oct, 2017 in Arizona) (reports that Waymo re-added safety drivers since Nov 2018	3 or 4 (human safety driver still used)	3 or 4 (human safety driver still used)	3 or 4 (human safety driver still used)	Tesla's Autop lvl 2 automat
Sensors	7 3D Velodyne Lidar, 4 SRR2 Radar, 1 Fwd ESR Radar, 10 HD CCTV Optical Cameras, 2 GPS Antennas	2 Velodyne VLP16 Lidar, 2 IBEO Scala Lidar, 1 Hakuya Lidar, Radar (Future), Ultrasonic (Future), 2 ZED Optical Cameras, 2 Mayser Bumper Switch, Ellipse N GPS	2 360° multi-layers Lidar, 6 180° mono-layer Lidar, front/rear cameras, odometry (wheels encoder + inertial unit), GPS RTK, IMU,	3 360° VLP Velodyne Lidar, 7 145° SCALA Valeo Lidar, 4 Radar, 6 cameras, Inertial Measurement Unit (IMU), Wheels encoder + engine odometer, GPS RTK	Lidar, Radar, cameras,	Lidar, Radar, cameras,	Lidar, Radar, Cameras, Differential GPS, Inertial Measurement Unit (IMU), Odometry	Lidar, ultrasound radar, cameras, magnetic embedded into road with magnetic reader under the GRT to measure its position	6 Lidar (3 types: long-range,medium-range,short-range w/ wide field of view), Radar, custom vision system (8 vision modules w/ multiple sensors & forward-facing high-res multi-sensor module)	6 Lidar (3 types: long-range,medium-range,short-range w/ wide field of view), Radar, custom vision system (8 vision modules w/ multiple sensors & forward-facing high-res multi-sensor module)	5 Velodyne Lidar, 8 long-range Radars, 10 ultra-short-range Radar, 3 articulating Radar, 14 cameras	2 Lidar, Radar, cameras (front and rear facing), inertial measurement unit, (# of Radar, cameras not provided)	4 short-range Lidar, 5 long-range Lidar, 6 electronically scanning radar (ESR), 4 short-range radar (SRR), 1 trifocal camera, 1 traffic light camera, 2 GPS antennas,	No Lidar, Fro cameras, 12
Communication/Data	4G LTE GSM, On-Board Data Recorder	CANbus, Ethernet (Wi-Fi), DSRC (Future), GSM/LTE	DSRC, WiFi, 4G capabilities to transfer data such as shuttle position and pictures from shuttle cameras.	4G to communicate with the Navya supervision center			4G data connection network		HD Mapping (cars automatically send reports back to map team)	HD Mapping (cars automatically send reports back to map team)				Internet conn software upd maps,
Connected Vehicle Tech (V2I, V2V, V2X)			MARBEN V2X software, Autotalks V2X hardware devices	V2X supported	V2I supported. (streetlights, road signs)		V2X tech to communicate with environment and supervision center with 4G data connection				Not currently implemented		Dedicated short-range communications (DSRC)	
Passenger Capacity	14 Passengers (10 seated and 4 standing)	9 (EMEA) 12 (USA)	15 Passengers (11 seated and 4 standing)	Seats 6	Seats 6	Seats 6	15 Passengers	22 Passengers (8 seated and 14 standing)	Seats 7	Seats 5	Seats 5	Seats 5	Seats 5	Seats 5
Range	40 miles (Nominal). 25-30 miles (Max Load & Max AC)	32.4 miles	9 hours of theoretical average autonomy	10 hours of theoretical average autonomy	48 miles	48 miles	Up to 14 hours	50 km (31 miles)	32 miles electric. 488 miles gas	234 miles	238 miles	602 miles (city). 574 miles (highway)	324 miles (city). 450 miles (highway)	324 miles (ci (highway)
Energy	Electric. 18.5 kWh lithium-ion battery pack		Electric. 33 kWh battery pack LiFEP04	Electric. 22 or 33 kWh battery pack LiFePO4	Electric. Lithium-Ion 12.4 kWh	Electric. Lithium-Ion 12.4 kWh	Electric. 8 kWh Lithium LiFePO4 on 48V tension	Electric. Lithium-ion nano NMC, 2x 18.4 kWh	Electric/Gasoline. 16 kWh battery	Electric. 90 kWh Lithium-ion battery	Electric. 60 kWh Lithium-ion battery	Electric/Gas. 1.4 kWh Lithium-Ion battery.	Gasoline.	Electric. 100 ion battery
Engine/Motor	Protean Pd18 Hub Motor (x2)	EMRAX 228 High Voltage LC	Electric motor.	Electric motor.	AC Induction electric motor	AC Induction electric motor	Propulsion engine (electric asynchronous)	Central AC motor	Gas/Electirc V6 3.6 L	Electric Motor. 2 x 200 PS (150 kW) 348 N m (257 lbf ft) (total 400 PS (290 kW) 696 N m (513 lbf ft))	Permanent magnetic drive motor.	2 L 4-cylinder engine and electric motor	S63B44T4 4.4L V8 twin-turbo	Front and rea output up to 920 lb ft (1,2 induction mo
	Max Torque = 2500 Nm	Max Torque = 240 Nm												
	Continuous Torque = 1300 Nm	Continuous Torque = 125 Nm									Torque = 360 Nm		Torque = 750 Nm (553 lb-ft)	
	Max Power = 160 kW (215 hp)	Max Power = 100 kW	Max Power = 25 kW											
	Continuous Power = 120 kW	Continuous Power = 20 kW	Power = 15 kW (nominal)	Power = 15 kW	Power = 8.7 hp	Power = 8.7 hp			Power= 260 hp	Power = 293 kW (394 hp)	Power = 150 kW (200 hp)	Power = 140 kW (188 hp) Battery Power = 35 kW	Power = 441 kW (591 hp)	
Max Speed	25 mph	25 mph	25 km/h (15.5 mph)	90 km/h (56 mph). 50km/h (31 mph) (operating)	25 mph. 15-18 mph (operating)	25 mph. 15-18 mph (operating)	40 km/h (25 mph)	60 km/h (36 mph)	115 mph (estimated)	124 mph	91 mph	155 mph	250 km/h (155 mph)	163 mph
Curb Weight (vehicle wt. w/o occupants/ baggage)	2767 kg (6100 lbs)	1500 kg (3300 lbs)	2400 kg (5291 lbs)	2000 kg (4409 lbs)	770 kg (1696 lbs)	770 kg (1696 lbs)	2750 kg (6063 lbs)	4500 kg (9921 lbs)	4987 lbs	4702 lbs	1616 kg (3563 lbs)	3668 lbs	4372 lbs	4883 lbs
Gross Vehicle Weight Rating (Max operating wt. of vehicle with occupants/ baggage)	3720 kg (8200 lbs)	2500 kg (5500 lbs)	3450 kg (7606 lbs)	2500 kg (5512 lbs)	1361 kg (3000 lbs)	1361 kg (3000 lbs)		6418 kg (15022 lbs)	6300 lbs	5886 lbs			4850-5470 lbs	5732-5997 lb

: Template for Joint Base Myer-Henderson Hall Business Case Analysis Report

Demonstration Program
Using Commercial Technologies

Business Case Analysis Report

Autonomous Vehicle Shuttle/Smart Bases Program/Pilot at Joint Base Myer-Henderson Hall

1 September 2020

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Autonomous Vehicle Shuttle Business Case Analysis Report

CONTENTS

Autonomous Vehicle Shuttle Business Case Analysis Report

EXECUTIVE SUMMARY

This project focuses on the central research question, "How and why does an autonomous vehicle transportation option on Joint Base Myer-Henderson Hall impact mission readiness and assurance, transportation services and costs, and safety and quality of life?" The project was exploratory research using a mixed methods single-case study embedded design with multiple units of analysis that varied across the research lines of effort (LOE). Evidence included field and participant observation, data collection and documentation, archival records, interviews, and surveys. The research LOEs reflected the desire to answer many emerging questions related to the dynamic nature of autonomous vehicle (AV) technology during a field study in a comprehensive approach that included the seven LOEs outlined below (Figure 1) in order to inform future smart installation guidance and policies and AV related measures of effectiveness and performance.

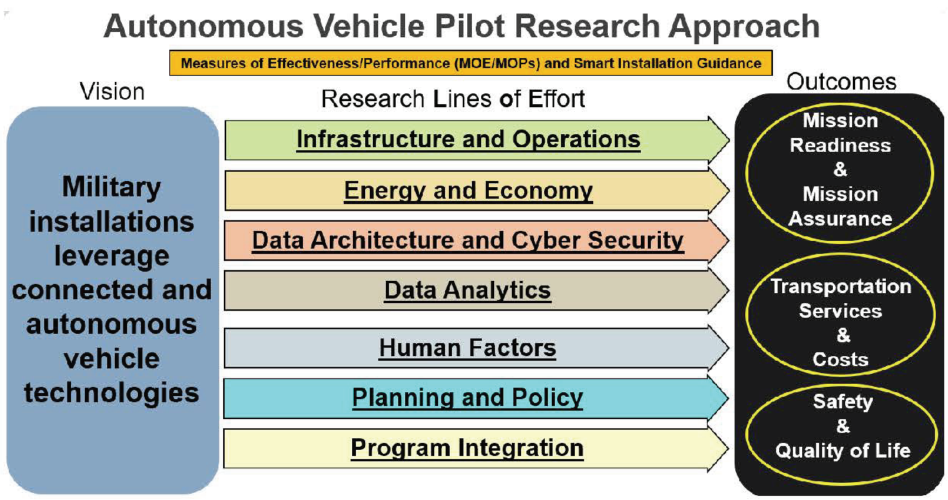

Figure 1. Seven research lines of effort (LOE) used for comprehensive analysis of the project

This pilot successfully demonstrated the viability and value of AVs on military installations with commercially available technology. Although AV technology has not yet matured to the point of widespread usage with standardized quality and safety standards, nor economic competition that provides a positive return on investment due to high initial technology cost, this project did demonstrate reduction in base operating costs, safe and flexible AV operations to improve quality of life with more transportation options on the base, and enhanced mission assurance and readiness through data analytics that provide operational information, edge computing, and viable AV services to address multiple use cases. Investing in additional pilots that encompass a broad spectrum of mission sets, topography, and climates will shape AV technology development, hasten adoption of AV technologies on installations as they become economically advantageous, and allow exploitation of real-time data fusion and AI technologies to build readiness and resilience in the strategic support area (SSA). We recommend the Army continue investment in this space, by expanding smart technology and AV pilots at different locations to confirm outcomes, test other SSA mission applications, address vulnerabilities, and scale the technology to discover points of diminishing returns.

The Army is seeking to integrate innovative technology into the operations of installations to support readiness, build resilience, increase efficiency, lower costs, and improve the quality of life of service members and their families. To accomplish that, the Army is conducting a series of technology pilots to demonstrate success or failure for implementing commercially available technology within Army installations.

Any test and demonstration program will include a cost-benefit analysis of expected returns to the Army. An analysis on each pilot will be in accordance with the guidance and approach outlined in the Army's Cost Benefit Analysis Guide, as prepared by the Office of the Deputy Assistant Secretary of the Army (3rd Edition, V3.3, 21 January 2020). Such an analysis must include, but is not limited to, a financial return on investment.

Readiness is one of the Army's three stated priorities, and an important consideration for return on investment. Technologies in a test and demonstration program must include measures related to supporting a given installation's ability to generate readiness and achieve its stated mission. Specific areas that contribute to readiness include improvements in training, safety, security, warfighting operations, power projection, maintenance and quality of life.

Resilience, in the context of an Army installation, is the ability to quickly recover from a shock and maintain operations. Following the discussion above on risks, resilience is crucial in the current environment of constant attack. Each pilot must clearly include an element that measures whether the technology enhances the installation's ability to protect and recover from an adverse event, whether manmade or from natural causes.

Looking to the future, the Army must consider the contributions that any tested technology has on the quality of life experienced at an installation, and whether that technology influences the recruitment and retention of current and future soldiers. Communities around the world are developing "smart spaces" that improve the delivery of public goods and services, provide convenience and/or save time. The Army must offer similar environments. Smart installations will be a more appealing environment to work and live for the future Solider.

1 Problem Statement, Objective and Scope

1.1 Background

Military installations serve as strategic staging areas which are integral to national security and require contemporary research and development efforts to explore and exploit rapidly changing innovations such as autonomous vehicle (AV) technology. This report documents the deployment of AV technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90-day pilot study from June 19th to September 27th, 2019 in order to evaluate the commercially-available Olli AV manufactured by Local Motors, Inc. and Robotic Research, LLC.

The Army is reconsidering how it views its installations as part of the battle space under Multi Domain Operations (MDO). This review includes technology modernization efforts. Connected and autonomous vehicle (CAV) technology is expanding rapidly. The DOD community and military installations have an interest in understanding autonomous transportation systems in order to plan for a broad range of areas that include infrastructure, security, economic impacts, cyber and communications. CAV demonstrations have been conducted on Army installations through the U.S. Army Research Laboratory (ARL) and the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC), Ground Vehicle Robotics program entitled Applied Robotics for Installations and Base Operations (ARIBO). The ARIBO program demonstrated CAV use on installations and matured the technology through increasing stages of chauffeured, safety operator, and fully autonomous vehicle operations within limited internal installation routes. The ARIBO projects occurred from 2015 to 2018 at locations including Fort Bragg, NC and West Point USMA, NY. The ARIBO program is no longer active, and with the establishment of Army Futures Command, the reorganization has resulted in institutional expertise at ARL and the newly formed U.S. Army Combat Capabilities Development Command (CCDC) Ground Vehicle Systems Center.

The Army now needs to conduct pilot projects that deploy updated and commercially available CAVs on installations and within adjacent communities to further demonstrate their use, and conduct research and development to optimize and inform the integration of this emerging technology. The above mentioned commands will continue efforts in CAVs focused upon combat missions. ERDC leadership on this project builds upon its expertise in infrastructure, energy, data analytics, and planning for installations to understand and inform CAV deployments on installations. ERDC's efforts will improve mission readiness and inform decision makers at installations as they seek to establish a common operating picture to automatically identify integrated optimization choices using: Big Data, Predictive Analytics, and Artificial Intelligence (AI) that can be incorporated into the Virtual Testbed for Installation Mission Effectiveness (VTIME).

CAVs capture, store, and analyze tremendous amounts of data. Military installations in the future will serve as integrated platforms with a need to understand the data systems and processes involved in CAV deployments in order to create systems-of-systems with enhanced data analytics that not only facilitate transportation optimization, but deliver a broader situational awareness to the commander. Data must

Autonomous Vehicle Shuttle Business Case Analysis Report

be protected from external exploitation in order to overcome threats and ensure continuity of operations. CAVs and onboard sensors can serve an integral function in providing visualization, notification, automation, and fully informed decision-making at the installation operational level.

In February 2019 a collaborative submission for a CAV demonstration project was proposed to Local Motors, Inc. by Joint Base Myers-Henderson Hall (JBM-HH), Marine Corps Installations Command (MCICOM), and ERDC with the support of the Office of the Assistant Secretary of the Army (IE&E), DASA Strategic Integration as part of the 'Greater Washington Fleet Challenge'. On March 15, 2019 an official notice by Local Motors, Inc. of the selection of JBM-HH as the regional location for the demonstration was received. A sole source contract to acquire data from the AV sensors and weekly operational reporting from Local Motors during the AV demonstration was approved. This 90-day demonstration formed the Phase 1 military installation AV deployment that is the time frame for this report.

A broader regional effort by the Northern Virginia Regional Commission and its stakeholders to provide 'first and last mile' transportation options to local commuters and reduce the traffic burden in the regional highway system includes Phase 1 as well as follow-on Phase 2 and 3 projects that provide AV services from JBM-HH to key transit hubs and employment institutions such as Metro stations and the Pentagon. The envisioned timeline and phases of this broader regional effort is shown in Figure 2. The military liaison with the Northern Virginia Regional Commission (NVRC) is a key integrator between the many installations and the regional transportation plans.

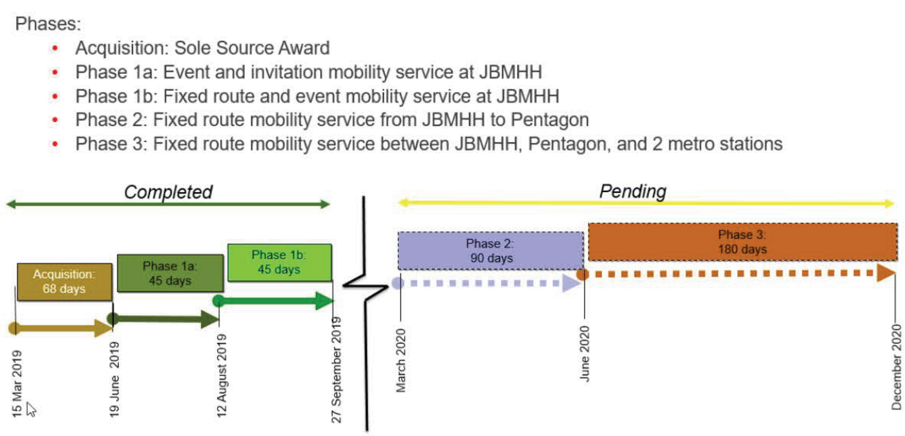

Figure 2. Timeline and envisioned phases for the deployment of AV technology in the Northern Virginia region. Phase 1 is complete and occurred completely on JBM-HH. The military liaison with the Northern Virginia Regional Commission (NVRC) is a key integrator between the many installations and the regional transportation plans.

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The federal roles and responsibilities for the JBM-HH deployment of CAVs were formalized in a federal Memorandum of Agreement (MOA). A summary of the roles is:

- ERDC-CERL as research and development project and contracting lead
- JBM-HH as project operation and support lead
- ASA IE&E as strategic communication lead
- MCICOM as joint integration lead and strategic communication secondary lead

The anticipated timeline and key activities originally planned at JBM-HH included:

- April 3, 2019: Begin deployment planning and site survey
- April- mid May 2019: Infrastructure set up and operational testing, vehicle and route set up and operational testing
- Mid-June 2019: Mobility service begin operation
  - Phase 1 service: internal JBM-HH route for 90 days
  - Phase 2 service: addition of route from JBM-HH to Pentagon from day 91 to day 180 if milestones achieved
  - Phase 3 service: addition of route to two Metro stations at Rosslyn and Pentagon City from day 181 to day 365
- Deployment closure after 1-year operation

Due to limited resources from local and state stakeholders, the Phase 2 and 3 aspects of this project which would extend off JBM-HH are still pending and thus not included in this report.

1.2 Problem / Opportunity Statement

The central research question for the project was "How and why does an autonomous vehicle transportation option on JBM-HH impact mission readiness and assurance, transportation services and costs, and safety and quality of life?" The project was exploratory research using a mixed methods single-case study embedded design with multiple units of analysis that varied across the research lines of effort (LOE). Evidence included field and participant observation, data collection and documentation, archival records, interviews, and surveys. The research LOEs reflected the desire to answer many emerging questions related to the dynamic nature of AV technology during a field study in a comprehensive approach that included the seven LOEs (see Figure 1) in order to inform future smart installation guidance and policies and AV related measures of effectiveness and performance.

1.3 Objective/ Goal

The objective of this project is to explore the data captured and the process required to employ autonomous vehicles (AVs) during the Olli AV deployment at JBM-HH. This project will transfer data collected by the AVs and document process steps and findings during the planning, site survey, set up, operational test, demonstration, and employment of AV technologies at JBM-HH, and within the surrounding community for evaluation of commercially-available AVs like the Olli.

The long term goal is to understand the data systems and processes involved in CAV deployments in order to create systems-of-systems with enhanced data analytics that not only facilitate transportation optimization, but deliver a broader situational awareness to the commander. CAVs and onboard sensors can serve an integral function in providing visualization, notification, automation, and fully informed decision-making at the installation operational level.

1.4 Scope

The project scope included a 90-day time period of Olli operations. Olli #10 and Olli #13 representing the sequence of Olli's built by Local Motors were the AV utilized. Each Olli was version 1.0. The location of the pilot occurred completely within JBM-HH perimeter on installation roadways. Timeline and phases are depicted below in Figure 3 along with key milestones achieved and dates.

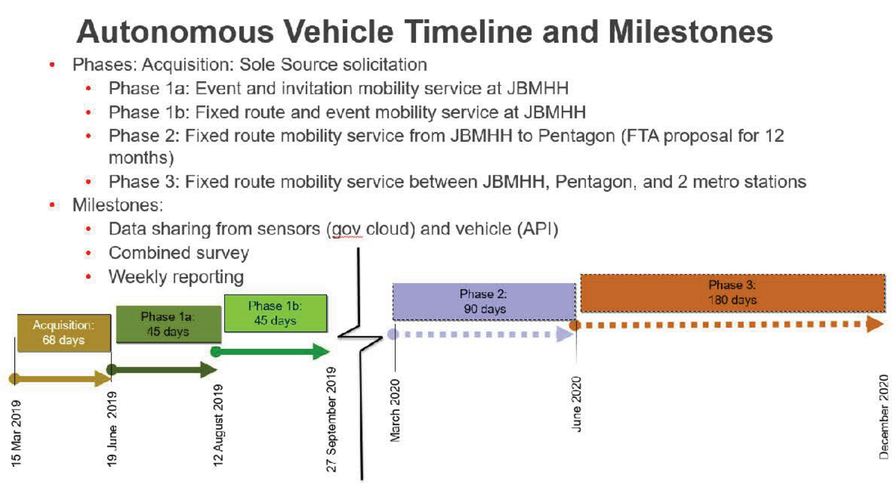

Figure 3. Timeline and milestones achieved

1.4.1 Significant Milestone Dates

4 April 2019: JBM-HH announced to be National Capital Region Local Motors Olli Fleet Challenge location for autonomous vehicle pilot.

16 June 2019: Federal acquisition process completed with award of sole source, firm fixed price contract to Local Motors for data transfer and process reporting during Phase 1. Two additional options included in contract continue data transfer and process

reporting during Phase 2 and 3.

19 June 2019: JBM-HH Launch Event and Olli begins Phase 1a operations for invitational events. Launch event speakers include Cathy McGhee, Director of Research and Innovation at the Office of the Virginia Secretary of Transportation; Jay Rogers, CEO and co-founder of Local Motors; along with Army and Marine Corps leadership.

12 August 2019: Phase 1a completed with total of 16 events and 171 riders on Olli for 0.9 mile demonstration route. Phase 1b operations begin along 4.4 mile fixed route from Wright Gate to South Gate of JBM-HH with 14 stops and two Olli AVs between 1100-1300 daily.

18 September 2019: Conducted afternoon roundtable at JBM-HH of all stakeholders to document project outcomes related to mission assurance and mission readiness, safety and quality of life, and transportation services and costs.

27 September 2019: Phase 1b completed with total of 7 weeks (35 days) of fixed route transportation service with over 450 miles traveled, 208 riders, 12 events, and 137 safety steward takeovers conducted.

2 Facts, Assumptions and Constraints

2.1 Facts & Outcomes by LOE

Below summarizes the outcomes of each LOE. Complete methodology, assumptions, and analysis data resides in Construction Engineering Research Laboratory publication, ERDC/CERL TR-DRAFT (in publishing).

2.1.1 Infrastructure and Operations

The infrastructure and operations LOE demonstrated AV shuttle service of two AVs along the main routes of JBM-HH in a circular pattern from Wright Gate to South Gate during a 2-hour lunch period on weekdays over 7 weeks and for special events throughout the 90-day pilot. Electric vehicle charging infrastructure is critical in meeting operational goals of the AV fleet. The AV operated using a geo-fenced mapped route which required 3 weeks for the technology to establish prior to transportation service availability, much longer than the anticipated few days planned for mapping. The AV operated successfully for 8,900 minutes of scheduled service, but inclement weather was a constraint. Existing roadway infrastructure on JBM-HH was capable of accommodating the AV, but the low 4 inch clearance was problematic at security check points, and maneuvering the vehicle on a 7% grade was challenging. Optimizing AV operations would require additions and modifications to loading/unloading areas, traffic signals, and other communication infrastructure. The AV team required parking, charging, maintenance, and office space on the installation during operations. Future infrastructure investment on installations should consider technology that communicates and integrates with AV systems as part of their planning process.

2.1.2 Energy and Economy

The energy and economy LOE analyzed vehicle control unit and telemetry data to conduct an energy consumption study with a comparative analysis of the battery management system data to the vehicle operational limits. Battery drainage of the AV was higher than expected during operations and is a constraint. While the average range for the AV specifications was 20 miles for maximum load and 35 miles nominal, the realized range was on the order of 16 to 19 miles, or approximately 55% of nominal. Cost of operational energy for the AV ranged from $0.05 to $0.08/mile driven; and $0.26 to $0.30/hr of operation during fixed route transportation service based upon the current price at JBM-HH of $0.07/kWh. Efficiency of AV operation ranged from 0.69 kWh/mile to 1.14 kWh/mile. A 10% loss in energy between the charging station power required and the battery charge received was observed in the data, which is a reasonable planning factor for converting operational energy demand to supplied energy. Energy usage and consumption for AVs varies greatly with context of operations. The data sets were disparate and difficult to integrate for evaluation of energy use, miles driven, hours of operation, vehicle status, and location in a time sequence that allows detailed econometric analysis. Future data indexing and collection should consider this in the data architecture design stage for determining data collection frequency, latency, and integration goals of the project.

2.1.3 Data Architecture and Cyber Security

The data architecture and cyber security LOE collected and analyzed data from AV sensors including LiDAR, radar, cameras, and vehicle telemetry data of 92,092 files at 6 terabytes which were transferred to a secure federal government cloud storage and are available for future data mining and analysis. The AV data and processing system on the vehicle had no reliance upon external network access which resulted in high security but a lack of real-time data transfer. Data transfer into secure government cloud storage occurred manually through periodic offloading via portable hard drives and overnight uploading with secure offsite internet connections. Edge computing and realtime data were limited highlighting the trade-off between risk and value. A standardized mechanism for indexing data from various sources of AV technology systems is needed to establish a solid data architecture and allow common data queries and effective application of post processing methods and data analysis. Developing and documenting physical, operational, communications, and cyber security assessment protocols will require further research studies and use-case applications with multiple AV technologies at varied installation locations with diverse missions. Both the data environment and the applications require an integrated security approach that is currently ill defined in the 4G and 5G networks.

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2.1.4 Data Analytics

The data analytics LOE examined potential exploitation of AV data for second order impacts that may benefit the installation. AV sensors and technology are deployed to prioritize and optimize data gathering and decision making for vehicle maneuver and navigation, and most of the artificial intelligence (AI) and data integration software for this purpose are proprietary products. Therefore, optimizing additional data analytics may require enhanced or additional sensors in the system. Reliability of the AV was uncertain based upon instances of hard reboot requirements for the onboard system which resulted in AV inoperability and data incongruity. Apparent fragility of the technology stack and integration with the AV sensor package demonstrated a need for continued development of more robust and resilient data processing and technology systems. A framework to count passengers onboard the AV with acceptable reliability using AI Cognitive Services was developed, but an effort to determine queue length of vehicles behind the AV through AI failed due to the low position of the external camera on the rear of the vehicle. Data mining review by time/location for incidents involving safety steward takeover of AV are possible but proved extremely time consuming. Integration of GPS or other location data is essential for real time data analytics. Edge computing use-cases that are most beneficial to installations for real time analytics should drive future investment in AI and supplementary sensor integration into current AV technology.

2.1.5 Human Factors

The human factors LOE examined the results of over 379 service members, families, and guests who rode the AV, with additional feedback from other users of the JBM-HH transportation system interacting with the AV as non-passengers. 154 surveys were gathered for analysis of trust in autonomy, basic demographics, and perception of safety. Results show AVs provide a perceived value to the installation and are considered intelligent, but comfort and trust have mixed responses. Riding the AV tended to increase trust in the vehicle. Ridership was much lower than expected, but may be attributed to limited duration and extent of deployment, lack of advance marketing or advertising, and challenge in changing human habits and behavior. Riders and non-riders want more transportation options on JBM-HH, but achieving the 'first and last mile' demands of users is a challenge and a better outreach mechanism is needed to inform people about the AV and its capabilities with links to transit hubs. Field observation determined low ridership for three primary reasons: 1) People wanted to know when and where Olli was operating and didn't have that information, 2) People didn't think it was safe and didn't realize the person onboard was a safety steward that could intervene if needed, 3) People didn't realize it was available for rides after the mapping period and did not know it was free of charge. The social nature of transportation adds complexity to AV and human interaction. The project survey data did not detect before and after perceptions of the safety of the AV, highlighting an opportunity for future research related to safety and how trust is gained or lost through the use of technology.

2.1.6 Planning and Policy

The planning and policy LOE determined that the state of AV technology systems, government regulation, and product integration into the market is not yet mature enough to recommend formal policy and procedures for military installations to adopt AV systems into their formal fleets. However, this study serves as a foundational baseline for future AV studies and the findings highlighted the need for more installation pilots to examine other AV systems deployed in varied use-cases, climates, topographies, and community settings. The project had no AV related injuries or crashes, however the low maximum speed of 12 mph disrupted normal traffic flow and identified a trade-off between risk and value, or risk and efficiency that requires more AV experience and technology development to determine policy. The use of AV technology must be incorporated with already proven transportation planning methodologies to ensure a holistic and deliberate approach that integrates transportation demands, origin/destination studies, infrastructure support, workforce requirements, user acceptance, accessibility, and local/state governance compliance on public roads.

2.1.7 Program Integration

The program integration LOE is an ongoing effort that explores how the application of AVs on installations impacts mission readiness and mission assurance in their function as Strategic Staging Areas under multi-domain operations and in the joint/interagency environment. Mission assurance impacts were examined through the 17 mission assurance areas that DOD has used to operationalize resilience. AVs demonstrated potential to impact each of these areas if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DOD and varied mission sets. AV technologies present opportunities to improve mission readiness/mission assurance and inform decision makers at installations, as well as leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work. The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the Northern Virginia Regional Commission (NVRC) pending funds availability. A 'way forward' matrix is proposed that identifies strategic future smart bases and AV pilot locations, geography/climates, academic partners, and joint force mission sets for a structured research and development framework that builds upon this foundational project.

2.2 Constraints

The project was exploratory research helping to better understand context and lay the foundation for further studies and demonstrations. The constraint of exploratory research is the smaller sample sizes, and hence the results cannot always be broadly interpreted and generalized. Exploratory research seeks to discover aspects of new research and technology and reveal problems and phenomenon associated with it. This exploratory research revealed additional questions and issues to take into consideration in future projects, and determined research priorities within the LOEs. Exploratory research is not well suited to derive a business case conclusion, but is foundational for developing quantitative measures and future comparative case studies.

3 Cost Framework

3.1 Cost Analysis

The 90 day pilot at JBM-HH afforded the opportunity to test AV technology on an Army installation. The cost of this 90-day pilot were shared by several participants: Local Motors- providing the vehicle and operating personnel; JBM-HH- providing logistical and promotional support; and the US Army ERDC-CERL- supporting the research lines of effort. The cost of the Olli itself has been estimate at $300,000. Local motors was responsible for the costs associated with delivery and return of the vehicle to JBM-HH. Local Motors provided two safety stewards and a project manager who were on site daily. One of these onsite personnel had to physically deliver the vehicle hard drive to their offices in National Harbor and back each day. JBM-HH provided the electricity for the vehicle charging and supporting equipment (antenna, utilities at charging station, etc). Two federal employees at JBM-HH took time prior to, during, and after the pilot to coordinate all aspects of the pilot. Researchers at ERDC visited JBM-HH frequently during the pilot to conduct surveys and collect data in each LOE. Costs associated with the operation of the AV itself are included in Chapter 6.

4 Alternatives

4.1 Way Forward

As a single case study, this project serves as a foundation for future comparative cases that will examine alternative AV solutions on installations. Chapter 6 of this report does compare the existing diesel bus operation as the current alternative to the AV option explored in the project. The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the Northern Virginia Regional Commission (NVRC) pending funds availability. A ‘way forward’ matrix is proposed (Figure 4) that identifies strategic future smart bases and AV pilot locations with known interest in future development, along with their unique geography/climates, academic partners, and joint force mission sets for a proposed structured research and development framework that builds upon this foundational project. An adequate sample of field sites and AV technologies is required before the lessons learned from this single case study can be integrated into formalized installation policy or regulation.

Location	Geography / Climate	Academic Partner	Mission Set
Joint Base Myer-Henderson Hall & Pentagon, Virginia	Urban environment, Atlantic coast, four seasons	George Mason University and Virginia Tech	Washington DC headquarters support
Ft Carson, Colorado	Mountains and high plains, high altitudes, four seasons	University of Colorado - Boulder	Combat Deployment: 4th Infantry Division (5 brigades)
Miramar Marine Corps Air Station, Naval Base San Diego	Desert and low mountains, Southwest temperate and Pacific coast	University of California – San Diego	Combat Deployment: Marine Air Wing National Force: Shipyard and Naval Support Group
Ft Leonard Wood, Missouri	Woodland, Midwest four seasons	Missouri University of Science and Technology	Institutional Training: Basic, Driver, Convoy, Engineer
Redstone Arsenal, Alabama	South-east region, low altitude, high heat and humidity	University of Alabama	Sustainment: Army Materiel Command
Ft Benning, Georgia	South-east region, varied terrain, high heat and humidity	Georgia Tech University	Combat Deployment and Institutional Training
Rantoul and Champaign, IL	Midwest plains, four seasons, intermodal transportation	University of Illinois	Smart Installation and Autonomy Research

Figure 4. Proposed "Way Forward" to investigate AV and smart base technologies

JBM-HH: This opportunity extends the route from JBM-HH to the Pentagon, and involves navigating a signalized traffic intersection. Higher risks in a congested urban environment, but higher visibility leading to higher ridership for 'first/last mile' needs.

Ft. Carson: This 2020-2021 pilot at Fort Carson, CO involves several AV use cases on an Army installation. The deployments will broaden the range of uses for AVs on Army installations, deepen the understanding of their impact, and can be compared to JBM-HH.

MCAS Miramar: This location will host both a 90 day Olli pilot in 2020 and a deployment of AV equipment in 2021-2022 yet to be determined. The 90 day Olli pilot will be beneficial for honing the research techniques employed at JBM-HH.

Ft. Leonard Wood: Opportunity to test and evaluate smart base and AV technology on an Army Installation and within a contingency base established as a field research lab.

Redstone Arsenal: Opportunity to test and evaluate smart base and AV technology on an Army Installation related to sustainment and R&D missions

Ft. Benning: Opportunity to test and evaluate smart base and AV technology on an Army

Installation with both combat deployment and training missions

Central Illinois: In close proximity to the ERDC laboratory, this location offers easy access to researchers for testbed projects on AV operations, sensors, data analysis, human interaction, policy and planning, and all lines of effort previously identified

5 Risk Assessment & Mitigation Strategies

5.1 Acquisition Risk

Technology advancements that improve the capability of AVs to address Army installation use cases are moving forward quickly, however, several risks will likely curtail adoption in the near term. These include sensors and data fusion, ongoing maintenance of the technology, safety of riders, government regulations and questions of liability and privacy, and cyber security. Risks discovered during the development, testing, acquisition and fielding of AVs from the JBM-HH pilot follows.

5.1.1 Technical Risk

Technical risk focuses on whether a given product or technology will fail to perform as intended or to a given set of requirements. In this context, the technical factors are still evolving within research and development programs. The JBM-HH case study provides the real world test environment to explore performance goals in an installation setting.

Sensors/Data Fusion: inability of sensors/software to correctly interpret and react in complex driving environments. Such was the case in construction zones. The AV sensors did not correctly asses the navigability of the constructions zones at JBM-HH.

Sustainment/Maintenance: Inadequate sustainment funds may prevent necessary vehicle maintenance including hardware and software upgrades. For example, the Olli AV utilized during the JBM-HH pilot has since developed a newer version with additional capabilities and more complex systems.

Safety/Operating Environment: Challenge in collecting data and confidence that it will meet current safety and performance requirements. A standardized safety certification for AVs does not yet exist in industry or government regulatory framework. Demonstrated safety or operational safety requires millions of miles of documented performance, which takes significant time and still may not address a comprehensive list of potential vehicle/person/environment scenarios. The pilot at JBM-HH produced just under 1000 miles of operation.

Legal/Liability: government regulation, insurance, and privacy issues. The JBM-HH pilot provided a unique environment for testing and research purposes, by not having to abide by federal vehicle regulations, the extent of vehicle interactions was somewhat limited and at low speeds. The vehicles were not proven on public roads where other vehicles and drivers could be less aware and may make improper assumptions about driverless vehicles.

Cyber: Inadequate cyber mitigation strategies in architecture may increase vulnerabilities and costs to sustain. During the JBM-HH pilot, there were negligible cyber security concerns due to the limited connectivity of the Olli AV. However, that is not the case with many other AVs, and even for newer models of the Olli. The risk associated with cyber-attack and malicious hacking is real, and could be a source of significant concern for transportation safety and security.

Human-to-Machine Interface: Ineffective communication and operational hand-off between vehicle/safety steward is an ongoing challenge for AVs that retain a 'human in the loop' component. During the pilot at JBM-HH, the number of trained safety stewards was limited and their training was limited to on-site practice with the AVs and roads on site. Operators of the AV were not the manufacturers or developing engineers, so their knowledge of the vehicle is limited to what is necessary to operate the vehicle on a day-to-day basis.

5.1.2 Business Risk

In the context of AVs, the consensus is AVs are going to be deployed in our cities within the next ten years. Recruitment of soldiers is challenging when you are asking them to disconnect from the smart city environment that they are accustomed to, and move to living on an installation that does not provide the latest technology and transportation options. Installations may consider not adopting AVs on the installation as a business risk until AVs are proven to be reliable and affordable.

5.2 Adversary Risk

Any technology deployed onto an Army installation could be subject to attack or exploitation by a future adversary. AVs will have to anticipate and defend against a full spectrum of malicious attackers wielding both traditional cyber-attacks and a new generation of attacks based on so-called adversarial machine learning. Olli operated independently—not connected to a network, and thus data security revolved around the physical security of the hard drive on the vehicle that houses the data. This is not realistic for all deployments. Connected features are essential, and adversary risk will exist at the enterprise level. The vehicle can also operate in manual mode. Without the presence of a safety steward, there exists the possibility of an unintended manual takeover by an adversary. If a kinetic attack occurs, this could even happen with a safety steward on board.

5.3 Mitigation Strategies

The current strategy to mitigate potential risks associated with AVs is a safety steward on board the vehicle. This single operator is required in the vehicle to monitor and take over when necessary. Safety stewards also accommodate accumulation of contextual data for safety verification of the AV. They can also recognize potential compromise and take back control of vehicle under cyber-attacks, inclement weather, or vehicle malfunctions. However, the presence of safety stewards adds to the cost of operating the AV and presents the challenge of machine-to-human operational hand-off.

6 Return on Investment

6.1 Quantifiable and Non-Quantifiable Benefits

The use of AVs yields several quantifiable and non-quantifiable benefits. Specific examples captured during the 90 day pilot with the Olli at JBM-HH are included in this chapter.

6.1.1 Quantifiable Benefits

Benefits which were quantified during this pilot include energy costs saved compared to current practices.

6.1.1.1 Reduced Cost

The Olli has an average operational energy cost of \$0.065 per mile, whereas the cost to operate the Myer Flyer is \$0.329 per mile. Assuming the shuttle route could be completed with either vehicle, the AV represents a significant savings in energy costs to operate.

6.1.2 Non-Quantifiable Benefits

Non-quantifiable benefits incurred during this pilot included: reduced emissions, reduced noise, reduced roadway degradation. Benefits which were not garnered from this pilot, but which could be potentially gained from AVs permanently deployed include increase morale if perceived ‘smart transportation’ improves quality of life; and increased transportation synergy and responsiveness if AVs are effectively integrated into the broader transportation network.

6.1.2.1 Reduced Emissions

The electric motor powered Olli produced no emissions during its operation. The elimination of combustion products is a significant benefit when looking at the overall impact of AVs on our environment and sustainability. If an AV were to replace a transportation alternative that did produce emissions, the reduction in emissions could be measured. However, for this pilot, the Olli operated in conjunction with existing public transportation options and therefore did not reduce overall emissions.

6.1.2.2 Reduced Noise Pollution

Similarly to emissions, the electric motor was silent and therefore did not produce noise pollution. This is a benefit in that any kind of pollution reduction improves sustainability and minimizes environmental impacts. The noise reduction was viewed positively at JBM-HH due to its proximity to Arlington National Cemetery with the somber and reflective quality desired in this context. However, one drawback from a safety perspective is the lack of warning this vehicle provides to pedestrians, due to the quietness of operation.

6.2 Costs and Benefits Comparison

In this section we compare aspects of the AV to the status quo diesel bus operating as the Myer Flyer at JBM-HH.

6.2.1 Operations Cost Comparison

A direct comparison of operation was conducted as a way to evaluate the cost-estimated difference between the currently in place 200hp diesel bus (Myer Flyer) and the Olli autonomous-electric vehicle to determine if the Olli would be a viable alternative for transporting individuals to and from JBM-HH and the Pentagon. Costs for mileage, lease, and a driver's hourly wage to operate each vehicle were determined, and a comparative analysis was completed assuming maximum utilization of both vehicles as the extreme case. In this comparison, it is assumed that the route will be operational Monday through Friday, for seven hours per day, resulting in an estimated 14,560 miles driven annually (based on information received from JBM-HH).

The cost to operate the Myer Flyer is $0.329 per mile. Over the course of a day (56 miles), this amounts to roughly $18.42 in operational costs, or $4,790.24 annually. The average passenger car operates at $0.076 per mile. Thus, the Myer Flyer costs roughly 4.3 times more in operational cost per mile than typical personal transportation. The average cost per passenger on the Myer Flyer is $0.275 for a 2 mile trip. Individuals would spend roughly $0.15 in operational costs to travel the same 2 mile route that the Myer Flyer services, but in their own personal vehicles. Increasing the number of passengers in either case reduces the operational cost per passenger proportionally. However, the Myer Flyer acts as a free service to riders meaning that individuals wanting to use the shuttle's service would not be prompted to pay any operational cost, while those taking personal transportation would. Cost comparisons are outlined in the table below.

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Table 1. Comparisons between Myer Flyer and Olli

	Current Mode	Proposed Mode
		
Vehicle	**Standard Bus (Myer Flyer)**	**Electric - Automated Vehicle (Olli)**
Power source	200hp Diesel Engine	135hp Max / 40hp Continuous Electric Motor (100kW Max / 30kW Continous)
Passenger Capacity	20 person	8 person
Management	GSA Fleet	Local Motors
Operation	M-F, 7 hours per day	M-F, 7 hours per day
Route	14,560 miles annually	14,560 miles annually

	Costs	Annual Cost	Cost	Annual Cost
Mileage Cost	$0.329 per mile	$4,790.24	$0.05 to $0.08 per mile ($0.065 Average)	$1,041.04
Cost Per Passenger	$0.275 per trip	-	$0.06 per trip	-
Lease	$28.83 per month	$345.96	$1000 per day	$365,000.00
Driver Cost	Driver, $27.51/hr, 8 hours per day	$57,220.80	Safety Steward, $30/hr, 8 hours per day (Included in Lease)	$62,400.00
	Total:	**$62,357.00**	**Total:**	**$428,441.04**

The Olli has a significantly less operational cost as compared to the Myer Flyer shuttle. The Olli has an average operational cost of $0.065 per mile with an assumed 10% loss of electricity during charging. Thus, the Olli would cost $4.00 per day or $1,041.04 annually. This represents a savings of $3,749.20 compared to the Myer Flyer. The Olli cost is $0.060 per passenger for each 2 mile trip. This is 8 times less than the Myer Flyer and slightly less than a typical passenger car. However, like the Myer Flyer, the Olli would be a free service to the passengers. These estimates only reflect the cost to operate the vehicle, and do not include maintenance, ownership/lease, or driver/safety steward.

The diesel bus or the Olli would be leased from the GSA Fleet or Local Motors respectively. This represents a large difference in cost given that the lease of the diesel bus would be a mere $28.83 per month while the Olli is priced at $30,000 per month (based on $1,000 per day). However, the Olli's lease includes the salary of the safety steward that maintains control of the vehicle in the event that human intervention is necessary. The salary of the Myer Flyer's operator is not included in its lease. Annually, the Olli lease is $365,000.00, including the safety steward's salary, while the diesel bus is $345.96, not including the driver's salary.

The salary of the operators for the diesel bus and the Olli are more com-parable. The hourly wage for the current diesel bus driver is $27.51 per hour for eight hours a day. This gives the driver a salary of roughly $57,220.80. The Olli's operator would get a similar wage of $30 per hour for eight hours a day, for an annual salary of $62,400;

however, as mentioned, this salary is included within the lease of the Olli. Due to the Olli's autonomy, the safety steward could theoretically be phased out over time. This would reduce the overall annual cost by a factor of the steward's salary, which would be a significant portion of the Olli's price.

The Olli does partially compensate for a higher lease price by its operational efficiency over the diesel shuttle bus. From test data collected at JBM-HH, the Olli cost between $0.05 to $0.08 per mile. Over the roughly 14,560 miles expected to be driven by the shuttle annually, this would produce a minimum, maximum, and average annual cost of $728.00, $1,164.80, and $946.40 respectively. As for the diesel bus, it costs approximately $0.329 per mile according to the fleet manager's calculations, reflecting an annual cost of $4,790.24. The Myer Flyer costs approximately $3,749.20 more annually to operate than the Olli.

Similar findings to this JBM-HH project resulted from a study done by Ohio State University in 2017 referencing the same make and model of the Olli and similar analysis comparing the use of an Olli to transport university materials across campus and act as a secondary mode of transportation for students as opposed to the university's fleet vehicles and shuttles (Henderson, et al, 2017, "Feasibility of Electric Autonomous Vehicles on Ohio State University Campus"). Ohio State University concluded that even purchasing an Olli from Local Motors outright was not a viable solution as the price of the technology still supersedes that of using a fleet vehicle or a shuttle to do the same task currently. The Olli out-performed in operational and maintenance costs of both the fleet vehicle and shuttle in the university's study, as well as went on to produce less carbon emissions overall. In the end, the initial $275,000.00 price tag of the Olli greatly outweighed that of the fleet vehicle and shuttle combined, regardless of any additional cost saved on fuel and maintenance.

Ultimately, the total cost comparison between the diesel bus and the Olli are operationally incomparable as the AV was only low speed and limited to on installation operation. It is roughly 6.9 times more financially efficient to operate the diesel bus as compared to the Olli, with the diesel bus having a yearly operational cost of roughly $62,357.00, while the Olli's would be $428,128.00. A vast majority of the diesel bus's yearly cost is allotted to the salary of the operator, which is roughly $57,220.80 as stated. This leaves a price of $6,703.96 to both lease and operate the bus on the determined route for the entire year. The relatively higher cost of the Olli is primarily due to the annual lease from Local Motors. Regardless of options to lease or purchase an Olli outright, the annual cost difference would still greatly outweigh that of the diesel bus, and documenting on-going maintenance and repair costs for extensive use of the Olli were beyond the scope of this project.

6.2.2 Transport Cost Comparison

The main considerations of public transportation options are capacity, serviceability, and efficiency when comparing alternatives. This section takes a transit services viewpoint to analyze and compare passenger travel options. The analysis is based on observations of the #9 shuttle route that provides passenger service from JBM-HH to the Pentagon's Transit Center using data and estimates for maximum capacity, person miles traveled, as well as the person-hours travelled annually. The comparison contrasts the Myer Flyer shuttle on the same route by either the Olli autonomous-electric vehicle or a personal passenger vehicle. The following costs have been assumed: national average gas mileage of 24.2 miles per gallon; national average cost of $1.841 per gallon of gas.

6.2.2.1 Myer Flyer Analysis

The Myer Flyer is one of 2 public transit systems between JBM-HH and the Pentagon, servicing an average of 67 individuals per day with a maximum capacity of 20 passengers at a given time. The Myer Flyer services the route for a total of seven hours a day during peak transit times in the morning and afternoon, five days a week, during every week of the year. The route is roughly four miles in length, round trip, taking roughly half an hour including multiple stops along the way. Thus, the total vehicle miles of travel (VMT) per day is 56 VMT or 14,560 VMT annually. For the purposes of this analysis, we assume the average passenger travels two miles during his or her ride. Thus, the total person miles of travel (PMT) is 134 PMT per day, or 34,840 PMT annually. The ratio of PMT to VMT for the Myer Flyer is 2.4.

Comparatively, a person driving their own car for any distance, the ratio of PMT to VMT is 1. For each additional passenger, the ratio doubles. Thus, the Myer Flyer represents the equivalent of a 2-3 person carpool. We note that it is unlikely that the Myer Flyer has approximately 2.4 passengers onboard at all times. Rather, it is likely that during periods of peak travel, there are higher numbers of passengers, and zero at other times. The maximum ratio of PMT to VMT attainable by the Myer Flyer could be 20.0 when all seats are filled, which is 4 times greater than an average passenger car's maximum ratio of 5.0.

For the Myer Flyer passenger onboard for 2 miles, he or she spends roughly 15 minutes traveling on the shuttle, thus accounting for 16.75 person hours travelled (PHT) per day (based on the average daily passenger count of 67). Annually, the Myer Flyer averages 4,355 person hours travelled (PHT), compared with 1,820 vehicle hours travelled (VHT). The ratio of PHT to VHT is also 2.4.

6.2.2.2 Olli Analysis

The Olli shuttle would theoretically yield the same results as the Myer Flyer for the vehicle and person miles travelled analysis along the JBM-HH #9 shuttle route. Utilizing similar ridership as the Myer Flyer, the Olli would achieve a PMT to VMT ratio of 2.4 (same as the current shuttle). Coincidentally, this is comparable to a 2-3 person carpool. The maximum ratio of PMT to VMT is 8, which would be achieved when the Olli is operating at maximum capacity. This ratio is less than half of the Myer Flyer's maximum ratio of 20, though still greater than a typical personal vehicle's ratio of 5. Due to the Olli's reduced capacity compared to the Myer Flyer, total volume of passengers transported along the route may suffer during peak transit times when demand is higher than what the Olli can support.

Assuming similar operation parameters as the Myer Flyer, passengers would spend roughly 15 minutes in transit along the 2 mile distance from the Pentagon Transit Center to JBM-HH, accounting for 16.75 Person-Hours travelled per day for 67 passengers a day average. An average of 4,355 PHT and roughly 1,820 VHT would likely be observed creating a ratio of PHT to VHT of 2.4.

6.3 Bill payers, Offsets or Tradeoffs

At JBM-HH, the bill for the Myer Flyer is covered by the Transportation Division of the Logistics Office. It is assumed the same office would cover the bill for an AV at JBM-HH. However, seeing as the overall cost of an AV (the Olli example explicated in section 6.2) is currently higher than traditional shuttles vehicles, additional funding sources would be necessary.

6.4 Second and Third Order Effects

Costs associated with smart infrastructure, signage, advertising, storage, maintenance, upgrades and disposal of physical aspects are all relevant when considering AV technology. However, the cost to capture, store, process, and safeguard data generated may be significant as well. AV technology is rapidly developing, such that what is popular and feasible now, may outdated in just a few years. The costs to update or replace with newer technology can be an ongoing expense. Data system integration, archiving, and safeguarding adds significant burden of management attention and direct cost for data storage. Documenting quantitative costs for these effects was beyond the scope of this project, but planning factors for these anticipated costs are an opportunity for future research.

7 Results, Recommendations and Conclusion

7.1 Results of Analysis

This project was a joint collaboration of the Army, Marine Corps, and industry elements to plan, develop, demonstrate, and employ autonomous vehicle (AV) technologies at Joint Base Myer-Henderson Hall (JBM-HH) for a 90-day pilot study from June19th to September 27th, 2019 in order to evaluate the commercially-available Olli AV and assess the potential to enhance mission assurance and readiness, reduce base operating costs, improve safety and quality of life for military service members and their families, and provide transportation services more efficiently and effectively. Successful performance on JBM-HH during this time frame offers expansion into the surrounding community through cooperative efforts with state and local governments of the Northern Virginia

Regional Commission (NVRC). This project advances past research and will enhance installation understanding of the process, infrastructure, human factors, and data systems involved in AV deployments in order to leverage it for internal optimization and protect it from external exploitation.

People: Over 379 service members, families, and guests at JBM-HH had the opportunity to ride the Olli AV, with many more interactions occurring while utilizing the base transportation system. Over 154 surveys were gathered for feedback on their experiences during the 90-day deployment.

Product: AVs provided shuttle service along the main routes of JBM-HH in a circular pattern from Wright Gate to South Gate during a 2-hour lunch period on weekdays over 7 weeks and for special events throughout the 90-day pilot. Data from AV sensors including LiDAR, radar, cameras, and vehicle telemetry of 92,092 files at 6 terabytes were transferred to a secure federal government cloud storage for future data mining and analysis. Vehicle control unit and telemetry data were evaluated as part of an energy consumption study with a comparative analysis of the battery management system data, the vehicle operational limits, and the existing GSA fleet diesel powered vehicle used as a shuttle.

Policy: The successful deployment of AV technology on JBM-HH proved viability within constraints, and sets the stage for Phases 2 and 3 within the surrounding community and the Northern Virginia Region to further answer remaining research questions. The current immaturity of fully autonomous vehicle technology limits wide deployment on military installations. Lessons learned are shaping the current planning and development of a Fort Carson, Colorado AV deployment and research projects for ERDC. The policy and planning implications captured will be published with other AV case studies, and inform development of military installation guidelines for AV technology in the future.

Partnership: The JBM-HH pilot enhanced federal, state, local, academic, and commercial sector cooperation and learning about AVs through weekly stakeholder synchronization meetings during the 90-day pilot, an Educational Partnership Agreement between ERDC and George Mason University, over 25 special AV events, and open invitations for government agencies and the public to experience the JBM-HH pilot. Partnering to demonstrate AV viability at JBM-HH while conducting research to quantify mission readiness impacts, transportation system requirements and effects, and cost savings of the technology introduced new relationships with several universities, USDOT, DHS, AASHTO, Cooperative Automated Transportation Coalition, and various industry AV manufacturers and providers.

7.2 Recommendations by LOE

7.2.1 Infrastructure and Operations

Existing road and roadside infrastructure was adequate for AV deployment with no major investments required to improve or change current system at JBM-HH prior to the pilot. All roads were two-lane traffic and all intersections were stop sign-controlled. An RDK antenna was provided by the contractor and temporarily installed on top of a building during the deployment in order to ensure GPS accuracy of the AV during operation.

Mapping and establishment of the base route took 3 weeks of AV on-site preparation, and additional routes were not added later in the project due to the cost and resources required to bring back the map-ping team, while the installation originally planned for only days to accomplish this task. Consider if mapping can be done in advance or develop standards and specifications for installation to deliver this to AV providers.

Traffic operations were sometimes impacted by the AV maximum speed of 12 mph with queues forming behind the AV. Numerous shuttle stop locations and two-lane roads with curb and gutter on each side restricted pull-out locations for the AV during fixed route operation restricting ability of other vehicles to pass the AV during loading/unloading of passengers. Planned shuttle stops would preferably allow the AV to pull over and stop for loading/unloading without impacting normal traffic operations.

Sufficient quantity, type, and location of electric-powered vehicle charging stations is critical for infrastructure and fleet management planning. One compatible and high-speed charger was available for the two Olli AVs on JBM-HH and this was purchased by the installation prior to the project and located in the AV storage garage.

Operation of the AV was constrained by inclement weather and darkness. Rain caused stopping of operations due to safety concerns over sensor reliability and wheel slippage. Heating and air conditioning caused increased battery usage. Operation was only in daylight during the summer, but cold weather and darkness would be expected to increase battery usage for heating and lighting.

Operation of AV constrained by environmental conditions. Examples included 'unlearned' scenarios of road construction, parked buses, or incidents requiring off-tracking from geo-fenced and mapped areas. Steeper grade of 7% from Wright Gate to Stop #3 increased battery usage and slowed the AV challenging its climbing and maneuver capability. Navigating over steel spike security strips employed at both Wright Gate and South Gate resulted in damage to one AV rendering it inoperable for one week. Typical ground clearance of the Olli with passengers was 4 inches and for military installation applications should be higher and similar to standard highway automobiles.

AV operations team required designated work space for team meetings, vehicle and tool storage and maintenance, data download, and standard office functions. The installation maintenance bay provided to the AV team was mostly adequate for the pilot, except for data transmission which occurred offsite. Ideally high-speed internet or 5G access along with a more robust office setting sized for the AV fleet and team would be incorporated into the AV parking and maintenance location.

7.2.2 Energy and Economy

Battery drainage of the AV was higher than expected during operations and is a constraint. While the average range for the AV specifications was 20 miles for maximum load and 35 miles nominal, the realized range was on the order of 16 to 19 miles, or approximately 55% of nominal. A single fast AV charging station was installed on the military installation and used to alternatively charge the two AVs.

The Olli has a maximum battery capacity of 18.5 kWh, but the fleet manager protocol was to ensure charge stayed above 20% of battery, thus if the vehicle did drop to 25%, the safety steward would immediately drive the vehicle back to the charging station location to ensure the vehicle did not lose power in a manner or place that was unsafe. This business practice should be considered in route selection, charger location, and overall planning.

Cost of operational energy for the AV ranged from $0.05 to $0.08/mile driven; and $0.26 to $0.30/hr of operation during fixed route transportation service based upon the current price at JBM-HH of $0.07/kWh. Efficiency of AV operation ranged from 0.69 kWh/mile to 1.14 kWh/mile. Energy usage and consumption for AVs varies with context of operations to include topography, temperature, vehicle and cargo weight, acceleration/deceleration zones, and additional battery loads such as heating/air conditioning, frequency of opening and closing of doors.

A 10% loss in energy between the charging station power required and the battery charge received was observed in the data. This is a reasonable planning factor for converting operational energy demand to supplied energy and cost.

Developing language for competitively bid AV mobility service should consider energy requirements and performance and whether government or contractor is responsible for each.

The data sets from the AV are disparate and difficult to integrate for evaluation of energy use, miles driven, hours of operation, vehicle status, and location in a time sequence that allows detailed econometric analysis. Future data indexing and collection should consider this in the data architecture design stage for determining data collection frequency, latency, and integration goals of the project.

Understanding the full range of data collected by the vehicle control unit and battery management system is useful in developing use-cases for AV sensor data and second-order benefits of AV deployments such as condition assessments, facility monitoring, or emergency operations notifications.

7.2.3 Data Architecture and Cyber Security

A standardized mechanism for indexing data from various sources of AV technology systems is needed to establish a solid data architecture and allow common data queries and effective application of post processing methods and data analysis.

Data security for project was high, however, this was primarily due to the self-containment of the AV system on the vehicle with no reliance upon any external network access. Although this was secure, it also resulted in a lack of real-time data transfer. Data transfer into secure government cloud storage occurred manually through period-ic offloading via portable hard drives and overnight uploading with secure offsite internet connections. Edge computing and realtime data were limited in this configuration. This highlights the trade-off be-tween risk and value.

Reliability of the AV was uncertain based upon instances of hard re-boot requirements for the onboard system which resulted in AV in-operability. Apparent fragility of the technology stack and integration with the AV sensor package demonstrated a need for continued development of more robust and resilient data processing and technology systems.

Sharing data requires a specific intergovernmental agreement or memorandum of understanding that entails extensive legal review and is complex. Data sensitivity, privacy, ownership, stewardship, re-porting, restrictions, and disclosure are all important considerations.

The AV fleet manager or a key person on the AV delivery team needs to have CAC-access to the DOD network if they will interact with a DOD-approved system. This was not required during this pilot, but was noted as important for future considerations and data sharing.

Developing and documenting physical, operational, communications, and cyber security assessment protocols will require further research studies and use-case applications with multiple AV technologies at varied installation locations with diverse missions. Both the data environment and the applications require an integrated security approach that is currently ill defined in the 4G and 5G networks.

7.2.4 Data Analytics

AV sensors and technology are deployed to prioritize and optimize data gathering and decision making for vehicle maneuver and navigation. Most of the artificial intelligence and data integration soft-ware for this purpose are proprietary products.

Raw sensor data from AV LiDAR and cameras were processed into video feeds for visual assessments and review, however, this was not done in real-time and requires large data storage capacity for HD video files. Video analysis of safety steward interventions proved challenging as searching accurate time stamps for interventions and viewing various sensor data to fully understand context was extremely time consuming.

ERDC developed a framework to count passengers onboard the AV with acceptable reliability using Artificial Intelligence (AI) and Cognitive Services.

ERDC attempted to use Cognitive Services to develop an AI frame-work to determine queue length of vehicles behind the AV, however, the external camera location on the rear of the vehicle was too low to do so with acceptable reliability. Further research is needed to determine if a camera on top of the AV or remote sensing is feasible for real time queue detection.

Data mining review by time/location for incidents involving safety steward takeover of AV are possible. Integration of GPS or other location data is essential for real time data analytics.

Edge computing use-cases that are most beneficial to installations for real time analytics should drive future investment in AI and supplementary sensor integration into current AV technology.

7.2.5 Human Factors

A 21 question survey was approved through IRB process for human subject's research with 154 surveys used for analysis of trust in autonomy, basic demographics, and perception of safety. Results show AVs provide a perceived value to the installation and are considered intelligent, but comfort and trust have mixed responses. Riding the AV tended to increase trust in the vehicle.

It is recommended to determine transportation goals, user origin/destination, and mobility patterns prior to an extended AV implementation. Overall ridership was much lower than expected, but may be attributed to limited duration and extent of deployment, lack of advance marketing or advertising, and challenge in changing human habits and behavior. After posting flyers with operational times and locations in more public spaces there was an increase in ridership.

Survey results indicate that riders and non-riders want more transportation options on JBM-HH, but achieving the 'first and last mile' demands of users is a challenge and a better outreach mechanism is needed to inform people about the AV and its capabilities. Recommend transportation service to transit hubs and expanding advertising beyond traditional public affairs print media to include social media, direct messaging through chain of command, and marketing to key audiences.

Field observation determined low ridership for three primary rea-sons: 1) Some people wanted to know when and where Olli was operating and didn't have that information. 2) Some people who had not rode the vehicle didn't think it was safe and didn't realize the person onboard was a safety steward who could intervene if needed. 3) Others didn't realize the Olli was available for rides after the mapping period and did not know it was free of charge as most transportation in the DC area has an associated cost.

Most riders thought Olli was safe and added value to the installation. However, the use of safety stewards adds complexity to risks and riders' safety perceptions. The project survey data did not detect before and after perceptions of the safety of the AV, which highlights the opportunity for future research related to safety and how trust is gained or lost through the use of technology.

The social nature of transportation adds complexity to AV and human interaction. The courtesy problem Building trust of an AV takes time, and safety is impacted by the fact that humans often do not follow the law, i.e. crossing solid yellow lines, tailgating, passing illegally, etc.

7.2.6 Planning and Policy

There were no safety incidences of personal injury for the duration of the pilot. Olli errs on side of safety and comes to a full stop before any potential issues arise. However, this behavior was disruptive to the existing traffic system, perceived by some as overly conservative, and resulted in some drivers risking illegal maneuvers to avoid the AV as noted in 'human factors'. This identifies a trade-off between risk and value, or risk and efficiency that requires more AV experience and technology development to determine policy.

Historically, the federal government has approved commercial vehicle types to operate on public roads at the level of the original equipment manufacturer, while state governments have approved individual drivers as operators and licensed specific vehicles. AVs combine these into a single entity and the design, crashworthiness, licensing, and insuring is currently ill-defined and unstandardized. Working with strategic partnerships like USDOT, states and regional partners near installations, and AASHTO on other pilots will inform this on-going process so military installations can integrate with the latest information, regulations, and priorities.

A long term transportation plan and study is needed to 'right size' AV fleet and supporting infrastructure to meet both system goals and user objectives. This process was compressed into a very short time period and done in reverse based upon available AV fleet and time period for the pilot study, but utilization of the transportation service was suboptimal.

Review of current installation planning documents and policies demonstrates a gap in addressing AVs. Developing a framework and guidance for future planning practice related to vehicle and fleet management, work force development, data sharing, security, legal, infrastructure and rights of way, and installation development considerations will require additional AV pilots at more installations.

Engage with first responders and public safety officials in the planning process. To ensure public safety, first responders and public safety officials (including police, fire, emergency medical services, and towing) need to have ways to interact with AV during emergencies. Responders and safety officials will need information and training to safely interact with AVs—including how to disable the vehicle, how to react if it is on fire, and how to move the vehicle.

Relationships and roles within the stakeholder group need to be clear. Participants ask things of others that they think are simple, but in practice may be easier said than done, or conversely, some hesitate to ask for fear of generating an overburdening request.

Appropriate messaging, public engagement and education activities to promote awareness, understanding, and acceptance of AVs, along with an engaged champion for the effort contributes greatly to the success. Ongoing communication to AV users and potential users with up to date information is also key to education and engagement activities.

Workforce development impacted the project as key positions of fleet manager and safety stewards were hired during the 90-day pilot. Planning for workforce hiring, training, and integration with an on-going AV service will help in communication and delivery of services on time.

7.2.7 Program Integration

Mission assurance impacts were examined through the 17 mission assurance areas that DOD has used to operationalize resilience. AVs demonstrated potential to impact each of these areas if an enduring and compelling use-case and supporting infrastructure is developed. Unmanned transportation services for personnel or supplies during a pandemic is one such use-case that can enhance mission assurance across DOD and varied mission sets.

AV technologies present opportunities to improve mission readiness/mission assurance and inform decision makers at installations, as well as leverage regional planning approaches that extend into the military installation community where much of the national and generating forces and their families live and work.

ERDC is collaborating with current Army Futures Command-CCDC Ground Vehicle Systems Center robotics and AFC Sustainment efforts. Findings of this project are fully integrating with ERDC Robotics Engineer Operations for combat engineering tasks and Ft Leonard Wood Contingency Base Technology Engineering Center AV test-bed.

Joint integration of the project is demonstrated by a follow-on re-search of an AV installation deployment which is planned for Marine Corps Air Station Miramar beginning in 2020, with potential to expand to Naval Base San Diego. Consultation with Joint Base Andrews is ongoing for Air Force AV deployment contract development and energy analysis.

The results from this project were shared at the kickoff meeting for the Fort Carson, Colorado AV deployment and research project for ERDC which builds upon JBM-HH. The policy and planning implications captured are shaping that effort and will be reported to Congress to inform development of military installation guidelines for smart installations and AV technology in the future

Multiple academic institution partnerships have resulted from this project. ERDC has completed an Educational Partnership Agreement and Cooperative Research and Development Agreement with George Mason University anticipating JBM-HH Phase 2, and several other university agreements are pending for related projects.

The JBM-HH project is planned to expand into the surrounding community through cooperative efforts with state and local governments of the Northern Virginia Regional Commission (NVRC) pending funds availability.

This research built upon previous Army Research Lab and TARDEC ARIBO program for wounded warriors at Ft. Bragg from 2015-2018

7.3 Value Proposition

Smart base and CAV pilots serve an important role in exploiting commercially available technology on military installations. It is important to test and demonstrate existing AV systems in operational situations in order to give personnel experience with the systems' capabilities, and then to develop requirements based on this experience. It is also evident that there are some unique requirements for which the Army installations must develop technologies that are existing gaps and not being pursued by the private sector. The long term goal is to understand the data systems and processes involved in CAV deployments in order to create systems-of-systems with enhanced data analytics that not only facilitate transportation optimization, but deliver a broader situational awareness to the commander and improve mission readiness. CAVs and onboard sensors can serve an integral function in providing visualization, notification, automation, and fully informed decision-making at the installation operational level. Thus, it is important for the Army to pursue the development of critical autonomous vehicle-related technologies integrated with holistic installation concepts as Strategic Staging Areas to accomplish future army missions.

Appendix B: Comprehensive List of Stakeholders

	STAKEHOLDER / WORKING GROUP MEMBER		ROLES / ACTIVITIES
Federal Government	US Army		
		Engineer Research and Development Center	Manage research activities
		Office of the Assistant Secretary of the Army, IE&E	Manage pilot coordination/publicity across Army
		US Army Tank Automotive Command	
		US Army Installation Management Command	
		Fort Carson	Pursuing AV pilot in FY20
		Joint Base McGuire-Dix-Lakehurst	Interested in pursuing AV pilot
	US Air Force		
		Joint Base Andrews	Interested in pursuing AV pilot
	US Navy		
		Marine Corps Installation Command, Joint Integration Team	
		Air Station Miramar	Pursuing AV pilot with the Olli in FY20
	US Department of Transportation		
		National Highway Traffic Safety Administration (NHTSA)	NHTSA carries out highway safety programs by setting and enforcing safety performance standards for motor vehicles and equipment
		Volpe	Research
	Washington Headquarters Service (WHS)		Invitational Rider
	U.S. Government Accountability Office on Installation Infrastructure Management Issues		Invitational Rider
Installation, State, and Local Government	Joint Base Myer-Henderson Hall		
		Garrison Command Office (Headquarters)	Oversight
		PAIO and Network Enterprise Center	Route Selection
		Public Affairs Office	Media/Outreach
		Directorate of Public Works	Mapping/Storage
		Directorate of Emergency Services	
		Directorate of Plans, Training, Mobilization, Security	Security/Citations
		Safety Office	Security and traffic violations
		Logistics Readiness Center	Invitational Rider
		Family Morale, Welfare and Recreation	Invitational Rider
		Equal Employment Office	Invitational Rider
		Child Development Center	Outreach
		Battalion Headquarters	Invitational Rider
		Pentagram	Outreach. Published routine articles regarding operations and milestones
	Virginia Department of Transportation		AV exploration
	Virginia Department of Rail and Public Transportation		Transit application
	Northern Virginia Regional Commission		Community and Military Liaison – Outreach

	Arlington County Government	Roadway
	Autonomous Vehicles Working Group, Office of the Deputy Mayor for Planning and Economic Development, District of Columbia	Invitation Rider
	Fairfax County Government	Invitational Rider
	Loudoun County Delegation	Invitational Rider
	Greater Washington Region Clean Cities Coalition	Invitational Rider
	Northern Virginia Transportation Commission	Invitational Rider
	Staff of Congressional Election Officials	Invitational Rider
	City of Alexandria, Department of Public Works	Invitational Rider
Industry	Local Motors	AV provider and operator
	Robotics Research	AV driving system provider
	Barbaricum	AV exploration
	Rand Corporation	AV exploration
	Booz Allen Hamilton	AV exploration
	Converge Strategies	Invitational Rider
	Dominion Energy	Invitational Rider
	National and Local Transportation Engineers (ITE)	Invitational Rider
	Blue Star Families	Invitational Rider
	American Association of Retired Persons (AARP)	Invitational Rider
Academi	George Mason University	AV exploration
	Virginia Polytechnic Institute and State University	AV exploration

Appendix C: Detailed List of PAIO Activities

C.1 Acquisition Phase

- Pursued options to bringing AV operations on base.
- Submitted a proposal with MCICOM and NVRC for the Greater Washington Olli Fleet Challenge.
- Established a Memorandum of Agreement (MOA) between ERDC-CERL, JBM-HH, and MCICOM, which served as the guiding authority-to-operate the Olli AVs on the installation.

C.2 Planning phase

- Allocated garage space at DPW maintenance building for two Olli AVs along with office space for the fleet manager.
- Procured charging equipment for AVs (approx. $3,000) and oversaw installation of the equipment by Directorate of Public Works.
- Defined AV shuttle route and operation times with Safety Office.
- Acquired permission for Local Motors to install a communication antenna on base. An RTK antenna was provided by the contractor and temporarily installed on top of a building during the pilot to ensure GPS accuracy of the AVs during operation.
- Ensured Local Motors fleet manager and safety stewards had access to base.
- Determined what, if any, rules for ridership were necessary (e.g., age restrictions, signed liability waivers).
- Organized Directorate of Emergency Services to inspect the Olli AVs. Directorate of Emergency Services devised action plans for how to handle Olli during emergency situations.
- Learned how to drive Olli in case of emergency.
- Participated in route mapping for local expertise of infrastructure and traffic patterns.

C.3 Operation phase

- Established a private online calendar to schedule Phase 1A invitational rides and maintain awareness of when Olli was operating and who was riding.
- Invited all departments on base to ride Olli during Phase 1A.
- Participated in all invitational ride events to answer questions and provide JBM-HH perspective of the pilot.

- Supported marketing initiatives including emails, flyers, and newsletter articles in coordination with PAO.

C.4 Closeout phase

- Participated in after-action reviews.
- Ensured all equipment was safely removed from base.

Appendix D: Partial Pentagram Articles

Pentagram

Vol. 63, No. 119 May 9, 2019 www.army.mil/jbmhh Published For Joint Base Myer-Henderson Hall

JBM-HH Tax Center identifies more than $3 million in refunds

By Katrina Moses
Pentagram Staff Writer

The Joint Base Myer-Henderson Hall Tax Center's closing ceremony was held May 1, and the numbers show how much preparers helped customers this year.

The tax center is open to military, their spouses, military retirees and their spouses. For the last five years, the center worked jointly with the Army and Marines.

"To the tax preparers, I told you — you were going to make a difference and you did," said Col. Francisco Vila, staff judge advocate, Joint Force Headquarters-National Capital Region and U.S. Army Military District of Washington. "Look at all the money people walked away with."

According to JBM-HH Commander Col. Kimberly A. Peeples, the center helped 1,187 customers for the 2018 tax year and prepared 2,173 state and federal tax returns.

Because the tax preparers provided free federal and state tax preparation, the tax center saved customers over $388,000 in tax preparation fees this season. The center identified over $3 million in tax refunds for customers.

Civilian volunteers and service members received an award during the ceremony from Capt. Caitlin Marchand, the legal assistance attorney from the U.S. Army Military District of Washington and tax center officer in charge, for their work at the tax center.

Pentagram Staff Writer Katrina Moses at kmoses@dcmilitary.com.

PHOTO BY KATRINA MOSES

(Right) Capt. Caitlin Marchand, the legal assistance attorney for the U.S. Army Military District of Washington and tax center officer in charge, prepares to recognize (left to right) Staff Sgts. Denmark Carmelo and Judy Cho during the closing ceremony for their work at the tax center.

Driverless vehicles delivered to JBM-HH

Self-driving technology came a step closer to reality on Joint Base Myer-Henderson Hall Tuesday and Wednesday with the deliveries through Hatfield Gate of Olli 10 and 13. Olli vehicles are the world's first self-driving, cognitive vehicles, and the joint base has been selected for research test routes. Completely fueled by electricity, Olli will go through the paces and test routes will be mapped on JBM-HH starting within the next 10 days. After being brought onto the base, the vehicles were brought to Bldg. 325 to be charged and stored. JBM-HH motorists, pedestrians and cyclists are being asked to not follow Olli too closely and avoid making the vehicles brake suddenly by running or driving in front of the shuttles. "Just treat it like a car," said Todd Hutchings, the JBM-HH information management officer, who is spearheading the Olli project. The shuttle can carry a maximum of eight seated passengers and carries standard heating and air conditioning systems. Olli's top speed is 25 mph and is nearly 13 feet in length. A human controller monitors Olli's operation and the safety of riders at all times.

PHOTOS BY JIM DRESBACH

Erin Mosman of the Plans, Analysis and Integration office receives the Joint Base Myer-Henderson Hall Civilian of the Quarter Award from Deputy Commander Marine Lt. Col. Mark Paolicelli and JBM-HH Command Sgt. Maj. Steven Harris April 24.

PHOTOS BY JIM DRESBACH

Tony Hansley is awarded a commendation for 35 years of federal service from Joint Base Myer-Henderson Hall Deputy Commander Marine Lt. Col. Mark Paolicelli April 24 at Joint Base Myer-Henderson Hall's Spates Hall.

Second quarter award ceremony held on JBM-HH

By Jim Dresbach
Pentagram Staff Writer

Joint Base Myer-Henderson Hall Deputy Commander Marine Lt. Col. Mark Paolicelli and Army Command Sgt. Maj. Stephen Harris presided over the joint base awards recognition ceremony held April 24 at Spates Hall.

A total of 47 joint base team members received individual, group or federal service awards.

Paolicelli addressed the gathering before the awards were distributed.

"As we slow down from 100 miles per hour, these moments are important to us to recognize all the hard work and say thank you for all you do," the deputy commander said.

The JBM-HH Civilian of the Second Quarter were awarded to Erin Mosman of the Plans, Analysis and Integration office and Michelle Jerney-Davis of the Directorate of Family and Morale, Welfare and Recreation. Team of the second quarter honors went to Child and Youth Services Management team of Lovonda Cockrell, Kerry Archam, Samar Brown, Jessica Smith and Elizabeth McGill.

Civilian of the quarter runner-up recipient was Deisy Rivas of the Directorate of Family and Morale, Welfare and Recreation. Team of the quarter runner-up was the Child and Youth Services Kitchen and Maintenance Team of Godchagon Leiner, Ricky Tyree, Christina Bensen, Grace Parker, Manoch Nampah and Chistopher Hummer.

Federal service award recipients were Tony Hansley (35 years); Edgar Lee and William Long (25 years); Victor Frye (20 years); Fidel Diaz, Letitia Douglas, Jason Luebke, Mason Scott Sullivan and Joseph Robert Thompson (15 years); Frank Chapman (10 years) and Nicholas Hairston, John Heath, Jr., Fran Marie Powers and Jay Scott Vaughters were recognized for five years of service.

A Civilian Service Achieve-

see AWARD page 5

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Local forecast

THURS.	FRI.	SAT.	SUN.
75 I 64	77 I 59	67 I 56	64 I 55

For more weather forecasts and information, visit www.weather.gov.

Pentagram

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TOG performs for Pittsburgh Marathon

PHOTOS BY SPC. JACOB PLANK

Soldiers assigned to the U.S. Army Drill Team, 4th Battalion, 3d U.S. Infantry Regiment (The Old Guard), preform for the Pittsburgh Marathon in Pittsburgh May 4.

Base to begin mapping route for Olli — level four autonomous vehicle

By Catrina Francis
Pentagram Editor

Editor's Note: This is part one in a three-part story series about Olli, a level-four autonomous vehicle that will conduct phase one data collection on Joint Base Myer-Henderson Hall.

Throughout history the Department of Defense has been at the forefront of innovation. To ensure DOD remains at the forefront, Marine Corps Installation Command and Joint Base Myer-Henderson Hall were selected as the winner of the National Capital Region Local Motors Ollie Fleet Challenge in April.

Although some might believe this is new technology, it's not. The technology for autonomous vehicles isn't new, said David Woessner, the vice president of corporate development and regulatory affairs with Local Motors. He added that there are different ways to think about autonomous vehicles. The current focus on autonomous vehicles really started more than a decade ago when Defense Advanced Research Projects Agency issued various challenges to technologists and research institutions to come up with vehicles that can drive themselves, he said. Some of this effort can be directly tied to work that DARP was doing in 2005, 2006 and 2007. There are five levels of autonomous vehicles and the vehicle that will be on JBM-HH will be a level-four vehicle.

"Level zero is defined by the Society of Automotive Engineers,

see OLLI page 7

PHOTO BY CATRINA FRANCIS

Olli, a level-four autonomous vehicle, will begin mapping and collecting data on Joint Base Myer-Henderson Hall.

Military leaders complete NDU's National Capital Region Joint Professional Development course

By Marisol Rivera
Henderson Hall
Pubic Affairs Specialist

Leaders from each of the Department of Defense military branches to include the Coast Guard, joined together for the National Capital Region Joint Professional Development course at the National Defense University, Fort Lesley J. McNair in Washington D.C., Friday.

The Joint Professional Development course was created to expand service members learning opportunities by integrating a joint context through enhancing the individual's ability to operate in a joint environment. The instructors consisted of senior enlisted leaders who represented each branch of service.

"It is very rewarding as a senior enlisted, and as a Marine, to not only teach to a large class but to receive feedback from the junior leadership on what is going on within the entire DOD to include the Coast Guard," said Marine Corps Master Sgt. Jimmie Cuevas, adjutant chief. "As instructors we are building relationships amongst ourselves, and cross pollinating our thought processes."

Each instructor was assigned a team of service members, which created a diverse environment among the branches of service. The members were split into five teams, each represented a branch of service, red team: Marine Corps, green team: Army, silver team: Navy, blue team: Air Force and gold team: Coast Guard.

Cuevas said the rationale behind five teams instead of one collective team allowed them to have smaller groups.

"Having teams allows for small focus group discussions, with the ability to look at each branch of service through a different lens, and respect what each others branch does for our nation," Cuevas said. "We all took the same oath, to serve and protect. The key part of the focus group discussions consists of cultivating critical thinking, critical leadership development; in topics such as cultural diversity, standards and discipline, ethical dilemmas, and customs and courtesy."

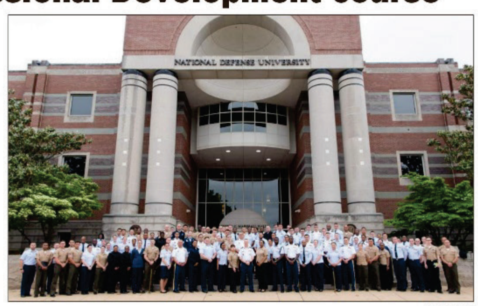

PHOTO BY NDU

More than 110 noncommissioned officers and petty officers from each branch of service across the National Capital Region attended the four-day Joint Professional Development course where they learned about operating in a joint environment.

As a part of the course on the second day, each group participated in a field meet. The purpose of the field meet was to build comradery and break down service identities to ensure the teams worked together jointly. This also fostered an environment for the branches to interact with one another.

"I learned a lot at the course, it helped me better understand and appreciate the culture of the other branches; their way of thinking, how they function, and the rolls they play as individual branches of the military," said Marine Corps Cpl. Victor Zagal, an administrative clerk.

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Pentagram

Vol. 63, No. 121 May 23, 2019 | www.army.mil/jbmhh | Published For Joint Base Myer-Henderson Hall

US Army Blues performs at the National Museum of African American History and Culture

On Sunday the U.S. Army Blues performed at the National Museum of African American History and Culture in Washington, D.C. The program featured The U.S. Army Blues with a musical lineup that included Nina Simone's "I Wish I knew What it was Like to Be Free," Curtis Mayfield's "People Get Ready," Sam Cook's "A Change is Gonna Come" as well as other songs.

U.S. ARMY PHOTOS BY STAFF SGT. VICTORIA CHAMBERLIN

Olli's research data can be used for more than driving conditions

By Catrina Francis
Pentagram Editor

Editor's Note: This is part two in a three-part story series about Olli, an autonomous level-four vehicle that will conduct phase one data collection on Joint Base Myer-Henderson Hall.

Using autonomous vehicles isn't a new concept to the Department of Defense. Jim Allen, a research and development lead from the Engineer and Research Development Center, said Fort Bragg had previously used an autonomous vehicle like Olli.

Two years ago Fort Bragg conducted a project where they transported wounded warriors from their housing area to the medical care facility on post. It's also been demonstrated at West Point and Local Motors technology is being used in the National Harbor area. The Maryland Department of Transportation has given them permission to operate on public roads in Maryland.

"It's proven technology, but it's still innovative and being developed," explained Allen. "The fact that it's transported people from point A to point B (safely) and securely has been proven to the point that we are ready to go to the next step.

"This next phase of doing it on an installation (is) to learn ... while it's doing that safe transport what else do we need to be concerned about? If that hadn't happened previously, they wouldn't have been authorized to operate on Joint Base Myer-Henderson (Hall)."

Marine Lt. Col. Brandon Newell of Marine Corps Installation Command said he is excited about the DOD, JBM-HH and other partnership because the research will allow the partners to unlock the future of autonomous

see OLLI page 5

PHOTO BY TODD HUTCHINGS

Olli, a level-four autonomous vehicle has began mapping on Joint Base Myer-Henderson Hall.

Missed appointments, no-shows at Andrew Rader Clinic affect patients, staff

By Katrina Moses
Pentagram Staff Writer

There has been a number of missed or "no-show appointments" at the Andrew Rader Clinic, and it has been more harmful than helpful to patients and staff, said Master Sgt. Latrevis Stokes, senior enlisted advisor for Andrew Rader Clinic.

"When you miss a medical appointment, it keeps another Soldier, Family member or retiree from using that appointment slot for medical care they really need," Stokes said.

He added that a no-show is defined as a patient who has an appointment who neither uses that appointment, nor cancels or notifies the treatment facility of their inability to keep the appointment.

Stokes pointed out that this affects multiple people. It affects the person who the appointment was for, another individual who could have taken the appointment and the government.

He warned that if an individual feels better before an appointment, still go to the appointment. He or she may learn that there are possibilities of having other health issues.

"Patients may have underlying conditions, possibly even life threatening that may impact multiple aspects of their lives, but if they continue to miss appointments, then those conditions will go unrecognized and or untreated," Stokes explained.

According to Stokes, in just the month of April, it cost the government $13,680 at Rader Clinic from all of the no-shows of the month.

Stokes said he understands life happens and someone can miss an appointment, simply by being in traffic. He said there is nothing wrong with calling to reschedule.

"An appointment can now be allocated because we can now give it to someone else," Stokes said.

It is beneficial to call at least 24 hours in advance to cancel an appointment.

Stokes said that an individual's unit or organization might have a penalty involved. This may be only because the unit or organization wants to make sure their Soldiers and Families are at their best health.

The appointment line for the purpose of canceling, rescheduling and booking appointments is (855) 227-6331. For more information, contact Stokes at (703)696-7929 or by email at latrevis.l.stokes.mil@mail.mil.

Pentagram Staff Writer Katrina Moses can be reached at kmoses@dcmilitary.com.

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Pentagram

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Autonomous vehicles could be wave of future

PHOTO BY CATRINA FRANCIS

Olli, a level-four autonomous vehicle has began mapping on Joint Base Myer-Henderson Hall as part of phase one of a pilot program. Phase one is being done on the joint base to gather research.

By Catrina Francis
Pentagram Editor

Editor's Note: This is part three in a three-part story series about Olli, an autonomous level-four vehicle that will conduct phase one data collection on Joint Base Myer-Henderson Hall.

Depending on when individuals were born, some watched TV shows, movies or cartoons with self-driving vehicles. Many believed that was just the imagination of the writer and those type of vehicles were possibly something in the far away future. But autonomous vehicles are in the present and have been for a few years.

As Joint Base Myer-Henderson Hall continues to conduct research with Olli — a level-four autonomous vehicle, the Army, Marine Corps Installation Command, northern Virginia, Arlington County and other counties in the state are waiting to see if phase one of the pilot program provides results to show having this kind of vehicle will be the present instead of the future.

Peggy Tadej, the northern Virginia regional director of military and community partnerships, said the partnership began with the joint base and its other partners because there was a need. She said the need in northern Virginia and Arlington County was the last-mile issue and her organization would also like to get people out of cars.

"Joint Base Myer-Henderson Hall is the largest employer in Arlington County and they have the highest for the region rate of single-occupancy vehicles," she said.

She pointed out that weather can sometimes impact an individual's last .7 mile of his or her commute. For example, if it's extremely hot or cold the individual may not want to walk in those conditions. Olli can possibly be the bridge to that problem and fix some of the

see OLLI page 10

Remembering those who sacrificed for America

PHOTO BY BY SGT. NICHOLAS T. HOLMES

Vice President Michael Pence, the 48th vice-president of the United States, participates in an Armed Forces Full Honors wreath laying ceremony during the 151st National Memorial Day Observance at the Tomb of the Unknown Soldier, Arlington National Cemetery, Virginia, Monday. Immediately following the ceremony, Pence delivered an address, at the Memorial Amphitheater, honoring those who gave the ultimate sacrifice while serving in the Armed Forces of the United States.

By Jim Garamone
Defense.gov

When Jane Horton hears someone say "Happy Memorial Day," it makes every one of her nerves stand on end.

"That's not what the day is about," the Defense Department's senior advisor for Gold Star and surviving family members matters, said.

Sure, Memorial Day marks the traditional beginning of the summer vacation season. The three-day weekend involves picnics and barbecues and family trips, but it is also about acknowledging the debt Americans owe those who died to protect the country.

"There is this one special day each year called Memorial Day, and that is the day to remember the fallen and those who have made the ultimate sacrifice," Horton said.

Memorial Day is a time for Americans to reflect on the sacrifices of so many to secure the country and protect its citizens. Since the country was founded, well over 1 million Americans have died in the nation's wars. Service members are still in harm's way in Afghanistan, Iraq and Syria.

Memorial Day grew out of the carnage of the Civil War, when more than 600,000 Union service members died giving the nation, as President Abraham Lincoln said, a "new birth of freedom." After such an overwhelming loss, Americans in the North and the South remembered those killed.

Arlington National Cemetery — created in 1864 to bury those killed in the Civil War's Overland campaign — was the site of family picnics on Memorial Day, as families from all over the country visited to place flowers on the graves of their loved ones.

PHOTO BY JOSHUA SEYBERT, AIR FORCE

Air Force Staff Sgt. Jared Arehart salutes the graves of fallen service members at the National Cemetery of the Alleghenies in Bridgeville, Pennsylvania, May 20.

Those who have paid that price were like Jane's husband, Army Spc. Christopher Horton, an Army sniper killed in Afghanistan on Sept. 9, 2011. Chris would want people to enjoy their long weekend, she said.

"But they should take some time to remember, and understand why they are free," she added. "That doesn't mean they have to be somber or they have to obsess over it. But they should keep the sacrifice in the back of their heads."

The best way to honor the fallen is to live the best life possible — especially for service members, she said.

"That's what I try to do," she added. "I have fun, go fishing, live the American dream, and remember, and learn different stories of those who paid the ultimate sacrifice for me."

Horton is worried that Americans are almost divorced from the losses suffered by those in uniform.

"People don't understand that this is real," she said. "They don't understand that people really do go to defend us so the enemy doesn't come here, and sometimes they die."

Horton is working on care and support to Gold Star and surviving families, "because we can always do better," she said.

"I'm also working to give more senior leaders access to Gold Star and surviving families," she added.

Horton said she wants senior leaders to understand how strong these families are, and that "the force needs to see that strength of the families left behind, and how we want to continue supporting the missions our loved ones gave their lives for."

Finally, Horton suggested that families know the names and know the stories of those who sacrificed for Americans they never met.

"Learn a name this weekend," she said. "Teach your kids a story about that loss. Then go and have fun."

Workforce development symposium provided chance for civilian employees to invest in themselves

By Katrina Moses
Pentagram Staff Writer

On May 21, more than 100 Joint Base Myer-Henderson Hall civilian employees attended the inaugural base workforce development symposium.

"I am definitely excited, and I hope you all are excited as well," Kathy Feehan, a workforce development specialist, said at the start of the day. "I hope today's professional development opportunity will meet your expectations and convey the command team's genuine appreciation of everyone."

Glenn Wait, chief of staff for JBM-HH, said that the event took a year to plan. The goal was to see, "how can we invest in our Army's civilians." He added that he wanted attendees to let him know what sparked their interest. The goal was to have the event grow each year.

JBM-HH's Commander Col. Kimberly Peeples was also a guest speaker at the event.

"Today was designed for you," she said. "This is a day to invest in your professional development in a way that best suits you."

James Bird Guess, CEO of JBG Success Academy, provided a motivational session called "Lead Like Water."

Guess, who created a $250,000 business from the trunk of his car, provided detail for "Lead Like Water." The goal was to use water as a metaphor of leadership. He explained that he watched one of Bruce Lee's final interviews. In the interview, Lee was asked about his fighting style. Lee explained that his fighting style changes for each opponent. The goal is to never become predictable when fighting — one must be like water.

Guess said water knows how to adapt. It knows how to be hard to be ice, waters

see WORKFORCE page 10

PHOTO BY EMILY MIHALIK

(Left) Bruce Walker listens while (center) Davis Tindoll, the director of Installation Management Command Sustainment, and (right) Glenn Wait, the JBM-HH chief of staff, explain federal resume writing during a break at the May 21 workforce development symposium.

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Pentagram

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Olli launch set for Wednesday

By Emily Mihalik
Joint Base Public Affairs

On Wednesday, Joint Base Myer Henderson Hall will formally welcome Olli — a level-four autonomous vehicle, to the joint base. Those in the JBM-HH community, including service members, Families, retirees and civilians are invited to attend the 1 p.m. launch. Community members may have already seen Olli out and about, mapping on the joint base as part of phase one of a pilot program.

The launch will be the first time the entire joint base community has the opportunity to meet Olli and learn about the data collection research project that is being conducted.

The Olli launch is especially significant to JBM-HH as it is a joint celebration, highlighting Army and Marine collaboration. Marine Corps Installation Command and JBM-HH were selected as the winner of the National Capital Region Local Motors Olli Fleet Challenge in April. The research derived from the project may allow partners to unlock the future of autonomous vehicles on installations throughout the Department of Defense. JBM-HH has a rich historical legacy of innovative and technological firsts, and Olli marks another step in the installation's history of innovation.

see OLLI page 4

PHOTO BY CATRINA FRANCIS

Joint Base Myer-Henderson Hall will hold a launch for Olli, a level-four autonomous vehicle, Wednesday in the Spates parking lot.

Pierce takes HQ Company command

By Jim Dresbach
Pentagram Staff Writer

The Headquarters Company United States Army guidon was passed to a new leader on Summerall Field Joint Base Myer-Henderson Hall Friday.

Capt. Shawn Pierce took command of the U.S. Army's largest company from Capt. Courtney Fuller while Lt. Col. Joshua Gillen, Headquarters Command battalion commander, presided over the affair.

Pierce, a former battalion adjutant for 4th Battalion, 3d U.S. Infantry Regiment (The Old Guard), now holds a unique leadership distinction. After 16 months as commander of Headquarters and Headquarters Company, U.S. Army Garrison, he now assumes the Headquarters Company United States Army — the two largest companies in the Army.

"Shawn is such an overachiever that command of the second-largest in the United States Army was not nearly challenging enough, so he has agreed to stick around for a bit longer and command headquarters company," Gillen said.

"Either I didn't get it right the first time or this is a do-over or I'm a glutton for punishment. I haven't seen my evaluation yet, so I'm probably pretty sure this is my do-over chance," Pierce joked during his remarks.

Pierce's former duty assignments included stops at Fort Drum, New York, Fort Leonard Wood, Missouri, and Guantanamo Bay, Cuba. He is a native of Kansas City, Missouri.

"I'm humbled for this honor," Pierce said. "This command is truly is test."

Fuller was in command of Headquarters Company United States Army for over 15 months before turning over command to Pierce.

Pentagram Staff Writer Jim Dresbach can be reached at jdresbach@dcmilitary.com.

PHOTO BY JIM DRESBACH

Capt. Shawn Pierce accepts the guidon from Headquarters Command Battalion Commander Lt. Col. Joshua Gillen during the Headquarters Company United States Army change of command Friday on Joint Base Myer-Henderson Hall's Summerall Field.

CDC pre-k students ready to start kindergarten

By Katrina Wilson
The Pentagram

Almost 20 students were adorned in cap and gown at the 9 a.m. Strong Beginnings graduation ceremony at Joint Base Myer-Henderson Hall's Cody Child Development Center Friday.

"It's hard to believe ... its time for their first graduation," said Tami McCarter, Cody Child Development Center director.

She emphasized to parents to take it all in that their child will soon be in kindergarten. She added that just like the Rascal Flats song, "Let Them

see STUDENTS page 4

Serenity Wright receives her diploma from Liza Popalzai Friday at the 9 a.m. graduation. Serenity led the alphabet chant at the graduation.

PHOTOS BY KATRINA WILSON

Students walking in for the 10 a.m. graduation at the Cody Child Development Center Friday.

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Pentagram

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Olli starts maiden voyage after launching on base

Olli, an electric-powered autonomous vehicle, begins one of its maiden voyages near Spates Community Club on Joint Base Myer-Henderson Hall June 19. Joint base commanders, Commonwealth of Virginia transportation officials and Defense Department staff members were the first passengers of the driverless vehicle, which has a 90-day pilot study on JBM-HH through August. See stories and more photos on Pages 6 and 7.

PHOTO BY JIM DRESBACH

Wiser assumes command at Henderson Hall

By Jim Dresbach
Pentagram Staff Writer

PHOTO BY JIM DRESBACH

New Headquarters and Service Battalion, Headquarters Marine Corps Henderson Hall Commander Col. Robert Wiser is congratulated by outgoing Commander Col. Keith Couch Friday during the change of command at Henderson Hall's Smith Gymnasium.

Headquarters and Service Battalion, Headquarters Marine Corps Henderson Hall has a new commander.

U.S. Marine Col. Robert Wiser assumed command from Col. Keith Couch Friday during the transfer of colors inside Smith Gymnasium.

Host for the change of command was Marine Lt. Gen. Michael Dana, Marine Corps staff director.

"This battalion is the most complex unit in the Marine Corps with literally people all over the planet," Dana said. "In this job, Keith and the team did a great job. You are absolutely a fantastic commander. You run an absolutely fantastic organization with no drama and positive leadership.

"We are going from one positive commander to another," Dana continued. "There's nothing like a command. You get to walk around and talk to young people. You will get to interact with Marines every day, and I wish you the best."

Couch served on the Henderson Hall deck and the joint base team since July 2017.

"What a fantastic group of officers and leaders I've had throughout the whole time here," Couch said. "This has been a true honor of my life to be your CO; I'm going to miss it. I'm truly lucky and honored to have had the opportunity to be a part of this wonderful team."

Wiser is a graduate of The Citadel and was commissioned in December 1994 through the Officer Candidate Class Program. He deployed to Afghanistan in June 2006 where he served as the transportation officer in the CJ-4.

"Your presence here today signals an importance and appreciation for the men and women in the Marines here at Henderson Hall," Wiser told the crowd. "I've had many leaders and mentors over the years that led me to this path. I thank them; I won't name them individually, but I will strive to live up to your investment in me."

Pentagram Staff Writer Jim Dresbach can be reached at jdresbach@dcmilitary.com.

JBM-HH to host fireworks on Whipple Field July 4

By Joint Base Myer-Henderson Hall
Public Affairs Office

On July 4, Joint Base Myer-Henderson Hall Independence Day fireworks will be held on Whipple Field.

Wright Gate will close at 1 p.m. to vehicular traffic. Pedestrians may still access the base through Wright Gate after 1 p.m.

Whipple Field opens at 5:05 p.m. for guests to arrive for the fireworks viewing.

Parking is in JBM-HH Tri-Services Parking, and individuals can walk to Whipple Field.

Approved visitor items at JBM-HH include: coolers, food and drink, clear plastic bottles, backpacks, strollers, diaper bags, chairs, blankets, seat cushions, cell phones, cameras (in accordance with JBM-HH photo policy) and service dogs. All items are subject to search.

Prohibited items include: weapons (firearms and knives with blades greater than 2.5 inches), grills, fireworks (to include sparklers), alcohol, glass containers, pets, laser pointers, drones, pop-up tents and running games such as football, baseball and Frisbee.

The fireworks begin at 9:07 p.m.

FILE PHOTO

Viewed from Whipple Field on Joint Base Myer-Henderson Hall, fireworks explode over the Washington, D.C., skyline for Independence Day

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Olli has autonomous vehicles riding through people's minds

Oops, Olli does it again

By Katrina Wilson
Pentagram Staff Writer

Olli, a level-four autonomous vehicle, was the main attraction Tuesday at a demonstration on Joint Base Myer-Henderson Hall when several state organizations were interested in learning more about the pair of autonomous vehicles.

The two Ollis were in rotation as they took members of Dominion Energy, George Mason University and Fairfax County around JBM-HH. For many of them, it was their first time on Olli and they inquired about the sensors on Olli, emergency stops and the autonomous and manual mode of Olli.

George Mason University's Sean Mallon, innovation and entrepreneurship, was in attendance. He discussed interest of cutting technology like Olli and human engagement. He said with technology like Olli, there is technology visibility, how people think of transportation and the underlying layer of technology.

Mallon said at GMU there are a network of shuttle buses that take students across campus or in between the school's campuses.

"We spend money running on a traditional shuttle," Mallon said. "Autonomous shuttle opportunities opens up opportunities to spend less money on something similar or more likely the same or more money for ubiquity of transportation. Instead of a bus every 15 minutes, a shuttle (can possibly run) every seven and a half minutes."

PHOTO BY PEGGY TEDEJ

Representatives from Virginia Department of Transportation, George Mason University, Fairfax County and Dominion Energy pose before taking a ride on Olli, a level-four autonomous vehicle.

He added that the question is, "how do you improve the experience of transportation for our students, faculty and other stakeholders?"

Dominion Energy's Julie Manzari, innovation strategist, pointed out how Dominion is looking at autonomous vehicles for emission stability.

"A lot of the autonomous vehicles are also electric," Manzari said. "We're very interested in connected-autonomous electric vehicles and learn through partnerships and pilots for what the market will look like in the future to better serve our customers.

Dominion Energy recently started a partnership with Fairfax County. According to Manzari and Eta Nahapetian, economic initiatives coordinator with Fairfax County, they have an interest in an autonomous vehicle traveling from Dunn Loring to Moziac Business District of Fairfax County. Nahapetian said that the area has a speed limit of no more than 25 mph and it is a highly trafficked area.

"Our goals include determining the operational viability of an autonomous shuttle as a first- and last-mile mobility solution, promote and expand Fairfax as a place for research and as a leader and innovator in smart community initiatives, of which connected and autonomous vehicle deployments are one example," Nahapetian said.

Being innovative is also Dominion's goal.

"We recognize that over the last 10 years, we made efforts in making our electricity greener with renewable energy resources and focus on that emerging technology with electrical vehicle projects," Manzari said.

Manzari also said the question is, "What will be the next step for autonomy?"

Virginia Department of Transportation's Amy Tang McElwain, program manager for office of strategic innovation, and Amanda Hamm, connected and automated vehicles program manger were at the demonstration as well.

"It is our job for the effective and safe movement of people across the commonwealth," Hamm said.

The duo said there is interest of having an autonomous vehicle on a public road and seeing how people react to Olli on public roads, intersections or how Olli would interact with vehicles infrastructure or signals.

"Once the vehicle goes off the base, we have different type of street markings, different size signings, different signals," McElwain said. "How will Olli interact with those things?"

She said VDOT wants to test signal change for an autonomous vehicle, such as how it will react at a stoplight's red, yellow or green lights.

The two said safety is a priority. McElwain said the speed of Olli on public roads is something to experiment and see. As well as the speed of other car's speeds near Olli.

"It is hard to control other people and what they do, but I want to see what Olli is going to do, and how other people interact (with Olli's speed)," she said.

Pentagram Staff Writer Katrina Wilson can be reached at kmoses@dcmilitary.com.

Appendix E: Timeline of Pilot Events and Activities

April

Day	EVENT / ACTIVITY
4	JBM-HH announced as winner of the Olli Fleet Challenge for the Greater Washington Metropolitan Area. MCICOM was the lead regarding JBM-HH's proposal submitted on 16 March.
18	Local Motors delivered data-sharing requirements to JBM-HH to begin setup.
—	JBM-HH and Local Motors meetings, discussion topics include communication infrastructure, garage space, and charging equipment on the installation.
—	JBM-HH purchased and installed required charging equipment. DPW identified and prepared garage space.
—	NEC drafted mobility route.

May

Day	EVENT / ACTIVITY
2-7	Local Motors delivered RTK to installation and installs.
—	NEC staff, in coordination with Safety Office, finalized AV mobility route.
10	Olli #10 and #13 delivered to installation. AVs get settled in the garage and charged.
13	Local Motors, in partnership with Robotics Research, begins mapping a subset of the mobility route. This turns out to be the demonstration route (Phase 1a).
—	Directorate of Emergencies Services briefed by Local Motors regarding Olli safety procedures.
14	Memorandum of Agreement signed between JBM-HH, MCICOM, and ERDC.
15	First weekly stakeholder meeting, discussion topics include establishing routes, 5G communications, garage space, and charging equipment on base.
22	Stakeholder meeting, discussion on planning the launch event.
29	Stakeholder meeting, discussion considered Amazon Web Services for data transfer.

June

Day	EVENT / ACTIVITY
3	VDOT and Navy joined stakeholder group.
5	Stakeholder meeting, discussion considered Microsoft Azure for data transfer.
12	Microsoft Azure Blob Storage established to receive data.
12	Arlington County joined stakeholder group.
12	Stakeholder meeting, discussion topics included: establishing milestones for Phase 1 and criteria to enter Phase 2; combining ERDC and Local Motors rider surveys; and processes for signing rider waivers.
13	Sole-source contract awarded between ERDC and Local Motors to exchange data.
19	Launch Event held at JBM-HH. 90-day pilot begins.
28	First invitational Olli-ride event held. Olli carries passengers along the demonstration route.
—	*Pentagram* published several articles regarding Olli operation on base. (Appendix D).

July

Day	EVENT / ACTIVITY
1-5	No invitational ride events held due to holiday.
8	Rider survey finalized and started distribution.
8	New LM Program Manager for fleet operations.
10	MCICOM applied to Olli Fleet Challenge, San Diego.
10	Vehicle sensor data successfully transferring via Microsoft Azure cloud.
17	George Mason University and Booz Allen Hamilton joined stakeholder group.
17	Stakeholder meeting, discussion included: initiation of fixed route mapping; data transfer logistics; and how to test traffic signal interactions.
—	New LM safety stewards trained for operations.
—	Fixed route (Phase 1b) mapping begins.
18	AV case study at JBM-HH briefed to NVRC Military Defense Communities bi-monthly meeting.
23	Meeting with AASHTO to ensure research lines of effort align with industry.
24	Stakeholder meeting, discussed transition between Phase 1a and 1b.
25	Discussion held with Washington HQ and Pentagon Parking Department regarding Phase 2 operations.
31	Completion of Phase 1a operations.
31	Joint Base McGuire-Dix-Lakehurst joined stakeholder group.
31	AV case study at JBM-HH briefed to Cooperative Automated Transportation Coalition.
—	FHWA announced that they are developing a readiness checklist to support AV deployment.
—	Chief Council looked at data dictionary regarding data share-ability and PII.
—	*Pentagram* continues to periodically publish articles regarding Olli operations. (Appendix D).

August

Day	EVENT / ACTIVITY
1-8	Operational pause—Local Motors provided safety steward training and reviewed fixed route operations, in cooperation with Robotics Research. Final route and operation times adjusted.
3	Energy meter placed in building housing the Olli AVs.
6	NVRC submitted grant proposal for Phase 2 operations.
7	Stakeholder meeting, discussion topics included operations. Noticed significant battery drain due to high temperatures.
12	First day of Phase 1b fixed route operations.
12	ERDC gained access to API for vehicle data transfer.
14	USDOT joined stakeholder group.
14	Stakeholder meeting, discussed traffic signal system testing and identified DRSC* as a requirement to mitigate risk.
14	LM installed sandwich boards to identify rider stops and installed signs on the rear of Olli reading “makes frequent stops.” Both actions were in response to observed issues.
21	Stakeholder meeting, discussed Local Motors operational reporting.
25	AV case study at JBM-HH featured on Washington, DC local network program, Emerald Planet.

* Dedicated Short Range Communications

28	Stakeholder meeting, ERDC shared preliminary data analysis.
—	*Pentagram* continues to publish route schedule.
—	Fixed route (Phase 1b) adjusted at a stop for convenience of riders.

September

Day	EVENT / ACTIVITY
4	Olli #10 lost bumper going over tire spikes near South Gate. Olli#10 was unable to provide a full shuttle service on 4-6 Sep.
4	Reduce air-conditioning onboard Olli during operations to preserve battery life.
11	Enduring low ridership spurred an increase in advertising. JBM-HH sent a base-wide email and posted route schedules at the bowling alley.
17	Olli 10 damaged while navigating tire spikes.
18	Stakeholder meeting, discussion of lessons learned throughout the project.
30	Final day of Phase 1b operations. Olli #10 and #13 shipped back to Local Motors.
—	*Pentagram* continues to publish route schedule through the month of September.

October

Day	EVENT / ACTIVITY
1	Local Motors removes RTK from installation.
16	Stakeholder meeting, closeout—discussion of recommendations.

Appendix F: Memorandum of Agreement

MOA-FY19-ERDC-CERL-[NUMBER]

MEMORANDUM OF AGREEMENT BETWEEN
THE U.S. ARMY ENGINEER RESEARCH AND DEVELOPMENT CENTER
CONSTRUCTION ENGINEERING RESEARCH LABORATORY (ERDC-CERL)
AND
THE JOINT BASE MYER-HENDERSON HALL (JBM-HH)
AND
THE MARINE CORPS INSTALLATION COMMAND (MCICOM)
FOR
SMART BASES: AUTONOMOUS VEHICLES PILOT

This is a Memorandum of Agreement (MOA) between ERDC-CERL and JBM-HH and MCICOM. When referred to collectively, ERDC-CERL and JBM-HH and MCICOM are referred to as the "Parties".

1. BACKGROUND: ERDC-CERL received funding from Congress to test autonomous vehicle (AV) technology as part of smart bases in FY19. JBM-HH has interest in AV technology demonstrations that date from a 2016 industry day at the base. MCICOM G7 program, Installation WerX seeks to explore, identify, and implement the newest and most efficient technologies and processes as they pertain to the development and management of installations. ERDC-CERL, JBM-HH, and MCICOM collaborated as part of a joint application for the Greater Washington AV Fleet Challenge to offer the JBM-HH location as a pilot site and for ERDC-CERL to receive AV data capture and reporting associated with an AV deployment. ERDC-CERL, JBM-HH, and MCICOM were notified on March 15, 2019 of the base selection for the AV deployment.

2. AUTHORITY: DOD Instruction 4000.19, "Interservice and Intragovernment Support", April 25, 2013

3. PURPOSE: The purpose of this MOA is to formalize collaboration between ERDC-CERL, JBM-HH, and MCICOM for the deployment of AV technology on JBM-HH in support of mutually beneficial research and development efforts that will explore the use of autonomous vehicles at military installations integrated with regional communities to lower costs, improve service member and family quality of life, and enhance mission readiness.

4. RESPONSIBILITIES OF THE PARTIES:

4.1. The ERDC-CERL will—

4.1.1. Function as the lead for Research and Development activity associated with the AV deployment including providing a Principal Investigator

4.1.2. Enter into a contract for data acquisition and delivery, and performance reporting to ERDC-CERL with the AV provider for data and processes that are generated during the operation of autonomous vehicles on JBM-HH

4.1.3. Distribute to all parties draft and final Research and Development products associated with the study, evaluation, and analysis of the JBM-HH AV deployment

4.2. The JBM-HH will—

4.2.1. Function as the lead for operations and support of the AV deployment on JBM-HH

4.2.2. Conduct and coordinate daily requirements and oversight of the mobility service provider to include providing a garage for AV storage, compatible charging station, and security.

4.2.3. Oversee AV mobility service provider set up, testing, route operations, and deployment closure for compliance with JBM-HH processes, procedures, and protocols.

4.2.4. Perform or assist AV provider with required mobility service advertisement and AV user notification and education

4.2.5. Function as the lead for public affairs operations associated with the JBM-HH AV deployment

4.3. The MCICOM will—

4.3.1. Function as the lead for the Olli Fleet Challenge submission and associated requirements

4.3.2 Function as the lead for strategic communication internal to the DOD

4.3.3. Coordinate milestone success/failure determination for Phase 1 and planning for Phase 2 and 3 as proposed in the Olli Fleet Challenge submission

4.4. All parties will—

4.4.1 Ensure communication with each other, their respective chains of command, stakeholders, and public affairs offices as part of the overall strategic communications document prepared by the Assistant Secretary of the Army for Installations, Energy, and Environment

4.4.2. Distribute to all parties draft and final products or joint publications associated with the Olli Fleet Challenge and the JBM-HH AV deployment

4.4.3. Allow all parties access to information, routes, equipment, and other necessary items to perform their responsibilities under this agreement.

MOA-FY19-ERDC-CERL-[NUMBER]

5. PERSONNEL: Each Party is responsible for all costs of its personnel, including pay and benefits, support, and travel. Each Party is responsible for supervision and management of its personnel.

6. GENERAL PROVISIONS:

6.1. POINTS OF CONTACT: The following points of contact (POC) will be used by the Parties to communicate in the implementation of this MOA. Each Party may change its point of contact upon reasonable notice to the other Party.

6.1.1. For the ERDC-CERL—

6.1.1.1 Primary POC: James P. Allen, Principle Investigator, ph: 217.737.1253

6.1.1.2. Alternate POC: Natalie Myers, Planning Lead, ph: 217.373.6741

6.1.2. For the JBM-HH—

6.1.2.1. Primary POC: Todd Hutchings, S6, ph: 703.696.0481

6.1.2.2. Alternate POC: ???

6.1.2. For the MCICOM—

6.1.2.1. Primary POC: Lt Col Brandon Newell, Chair of Mobility Transformation, ph: 760.500.4499

6.1.2.2. Alternate POC: ???

6.2. CORRESPONDENCE: All correspondence to be sent and notices to be given pursuant to this MOA will be addressed,

if to the ERDC-CERL, to—

6.2.1. 2902 Newmark Drive, Champaign, IL 61822

and, if to the JBM-HH, to—

6.2.2. 204 Lee Avenue (Bldg 59), Fort Myer, VA 22211

and, if to the MCICOM, to—

6.2.3. Building #2258, San Diego, CA 92145

or as may from time to time otherwise be directed by the Parties.

MOA-FY19-ERDC-CERL-[NUMBER]

6.3. REVIEW OF AGREEMENT: This MOA will be reviewed annually on or around the anniversary of its effective date for financial impacts and triennially in its entirety.

6.4. MODIFICATION OF AGREEMENT: This MOA may only be modified by the written agreement of the Parties, duly signed by their authorized representatives.

6.5. DISPUTES: Any disputes relating to this MOA will, subject to any applicable law, Executive Order, Directive, or Instruction, be resolved by consultation between the Parties or in accordance with DoDI 4000.19.

6.6. TERMINATION OF AGREEMENT: This MOA may be terminated by either Party by giving at least 30 days written notice to the other Party. The MOA may also be terminated at any time upon the mutual written consent of the Parties.

6.7. TRANSFERABILITY: This Agreement is not transferable except with the written consent of the Parties.

6.8. ENTIRE AGREEMENT: It is expressly understood and agreed that this MOA embodies the entire agreement between the Parties regarding the MOA's subject matter.

6.9. EFFECTIVE DATE: This MOA takes effect beginning on the day after the last Party signs.

6.10. EXPIRATION DATE: This Agreement expires on ________. [insert a date]

AGREED: [Approval Authority signatures will never be alone on a blank page]

For the ERDC-CERL—	For the JBM-HH—
______________________	______________________
Dr. Lance Hansen, Director	COL Kimberly Peeples, Garrison Commander

MOA-FY19-ERDC-CERL-[NUMBER]

For the MCICOM—

____
COL Che Bolan

____
(Date)

Appendix G: Example Weekly Report provided by Local Motors

JOINT BASE MYERS HENDERSON HALL (JBMHH) REPORT

16 August 2019

local motors by

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TABLE OF CONTENTS

local motors by

JBMHH Local Motors Manpower

3

Marci Patterson
Fleet Project Manager

Giovanni Medina
Safety Steward

Mike Nigro
Safety Steward

JBMHH July Ridership Summary

4

Organization	Installation	NVCR	LM	Totals
Events	7	7	2	16
Ridership	82	72	17	171

WEEK 1

DATE	RIDERS	EVENTS
8-Jul	2	Installation: DFMWR
9-Jul	11	NVRC: FFX County
10-Jul	18	Installation : DPW/HQs/EEO
11-Jul	5	NVRC: EPA
12-Jul	10	NVRC: Students
Total	46	

WEEK 2

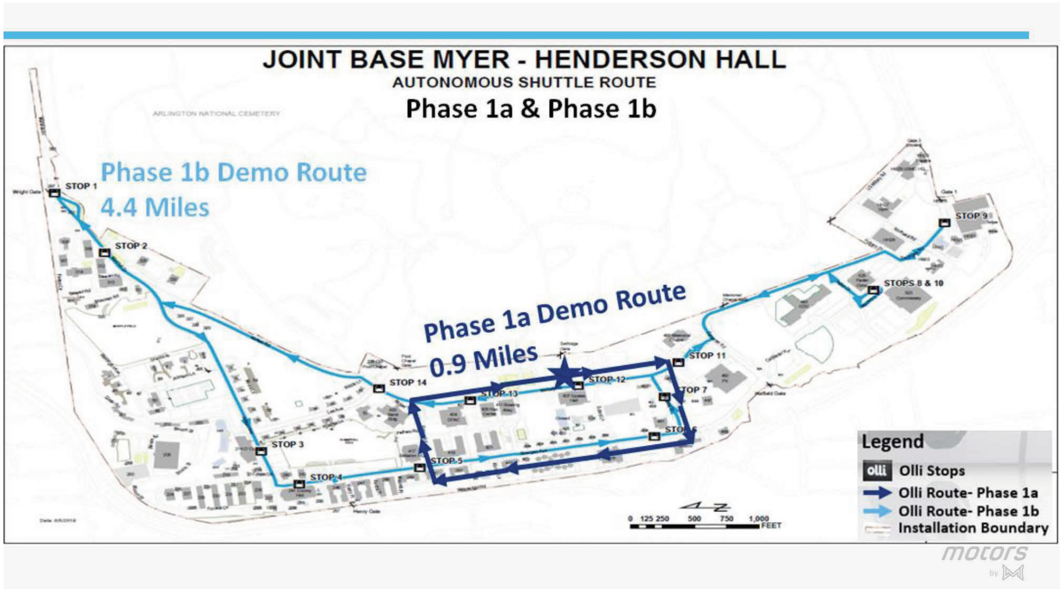
DATE	RIDERS	EVENTS
15-Jul	23	Installation: CDR MG Banta 9/LM: Kaust Visit 14
16-Jul	7	NVCR
17-Jul	Static Display	CMC Town Hall
18-Jul	Static Display	CMC Town Hall
19-Jul	1	Installation: DPW/DES/NEC
Total	31	

WEEK 3

DATE	RIDERS	EVENTS
22-Jul	N/A	Mapping Long Route
23-Jul	12	NVCR: NVTC
24-Jul	N/A	Mapping Long Route
25-Jul	18	NVCR: Pentagon
26-Jul	N/A	Mapping Long Route
Total	30	

WEEK 4

DATE	RIDERS	EVENTS
29-Jul	N/A	Long Route Training
30-Jul	9	NVRC: AARP
31-Jul	55	LM: Intel (LM) 3/Installation: Twighlight Tattoo 52
1-Aug	N/A	Training NH
2-Aug	N/A	Long Route Training
Total	64	



Bus 1			Bus 2		
STOP 1	Wright Gate	11:00:00 AM	STOP 1	Wright Gate	11:20:00 AM
STOP 2	Motor Pool	11:02:00 AM	STOP 2	Motor Pool	11:22:00 AM
STOP 3	Patton Hall	11:05:00 AM	STOP 3	Patton Hall	11:25:00 AM
STOP 4	Conmy Hall	11:07:00 AM	STOP 4	Conmy Hall	11:27:00 AM
STOP 5	Library	11:09:00 AM	STOP 5	Library	11:29:00 AM
STOP 6	Shoppette	11:13:00 AM	STOP 6	Shoppette	11:33:00 AM
STOP 7	Post Exchange	11:15:00 AM	STOP 7	Post Exchange	11:35:00 AM
STOP 8	Commissary	11:20:00 AM	STOP 8	Commissary	11:40:00 AM
STOP 9	South Gate	11:23:00 AM	STOP 9	South Gate	11:43:00 AM
STOP 10	Commissary	11:29:00 AM	STOP 10	Commissary	11:49:00 AM
STOP 11	Memorial Chapel	11:33:00 AM	STOP 11	Memorial Chapel	11:53:00 AM
STOP 12	Spates	11:36:00 AM	STOP 12	Spates	11:56:00 AM
STOP 13	Dining Hall	11:37:00 AM	STOP 13	Dining Hall	11:57:00 AM
STOP 14	Old Post Chapel	11:39:00 AM	STOP 14	Old Post Chapel	11:59:00 AM
STOP 1	Wright Gate	11:44:00 AM	STOP 1	Wright Gate	12:04:00 PM
STOP 2	Motor Pool	11:46:00 AM	STOP 2	Motor Pool	12:06:00 PM
STOP 3	Patton Hall	11:49:00 AM	STOP 3	Patton Hall	12:09:00 PM
STOP 4	Conmy Hall	11:51:00 AM	STOP 4	Conmy Hall	12:11:00 PM
STOP 5	Library	11:53:00 AM	STOP 5	Library	12:13:00 PM
STOP 6	Shoppette	11:57:00 AM	STOP 6	Shoppette	12:17:00 PM
STOP 7	Post Exchange	11:59:00 AM	STOP 7	Post Exchange	12:19:00 PM
STOP 8	Commissary	12:04:00 PM	STOP 8	Commissary	12:24:00 PM
STOP 9	South Gate	12:07:00 PM	STOP 9	South Gate	12:27:00 PM
STOP 10	Commissary	12:13:00 PM	STOP 10	Commissary	12:33:00 PM
STOP 11	Memorial Chapel	12:17:00 PM	STOP 11	Memorial Chapel	12:37:00 PM
STOP 12	Spates	12:20:00 PM	STOP 12	Spates	12:40:00 PM
STOP 13	Dining Hall	12:21:00 PM	STOP 13	Dining Hall	12:41:00 PM
STOP 14	Old Post Chapel	12:23:00 PM	STOP 14	Old Post Chapel	12:43:00 PM
END	Wright Gate	12:28:00 PM	END	Wright Gate	12:48:00 PM

(Phase 1b) Weekly Summary Data

7

12-16 August 2019

Date	Veh #	Start Time	Finish Time	Coordinator	Guest	Route Phase 1b .9 miles	Route Phase 1b 4.4 miles	Static Display or Manual not mapped	# of passengers AV mode	# of passengers Manual Mode	# of manual Takeovers (TKOs)	Reason for Takeovers (TKOs)	Takeover Response	Operational Hours	Operational Downtime	Reason for Operational Downtime	Operational Downtime Fix	Beginning Battery Charge	Ending Battery Charge
8/12	13	1100	1230	Installation	Bus 1 Shuttle Service	0	8.8	N/A	2	0	2	Not yielding and Software Issues	Pulled Ebrake reset error reengaged autonomous mode	1.30	0.00			79	34
8/12	10	1230	1330	LM	Pick Up Signs	0	4.1	N/A	0	0	0			1.00	0.00			83	61
8/13	10	827	941	LM	Place Signs	0	4.1	N/A	0	0	0			0.40	0.00			99	74
8/13	13	900	930	NVCR	VDOT	0.9	0	N/A	7	0	0			0.30	0.00			96	77
8/13	13	1100	1230	Installation	Bus 1 Shuttle Service	0	10.8	N/A	1	0	2	Stuck and Excessive Braking several parked cars along stop 4	TKO until pass stop 4 reengaged	1.27	0.00			98	43
8/13	13	1230	1330	LM	Pick Up Signs	0	4.1	N/A	0	0	0			1.00	0.00			43	34
8/14	13	906	953	LM	Place Signs	0	4.1	N/A	0	0	0			0.45	0.00			97	79
8/14	13	1100	1230	Installation	Bus 1 Shuttle Service	0	8.8	N/A	2	0	1	Parked Car	Drove Around reengaged	1.30	0.00			86	52
8/14	10	1230	1330	LM	Pick Up Signs	0	4.1	N/A	0	0	0			0.30	0.00			93	76
8/15	13	900	936	LM	Place Signs	0	4.1	N/A	0	0	0			0.36	0.00			98	77
8/15	13	1100	1230	Installation	Bus 1 Shuttle Service	0	8.8	N/A	0	0	1	Parked Car	Drove Around reengaged	1.30	0.00			77	42
8/15	10	1230	1330	LM	Pick Up Signs	0	4.1	N/A	0	0	0			0.26	0.00			99	80
8/15	10	1330	1425	Installation	MG McGuire	0.4	0	N/A	8	0	0			1.35	0.00			97	76
8/16	13	900	936	LM	Place Signs	0	4.1	N/A	0	0	0			0.36	0.00			57	37
8/16	13	1100	1207	Installation	Bus 1 Shuttle Service	0	4.3	N/A	0	0	0			0.58	0.00			97	59
8/16	10	900	1100	NVRC	Public Affairs	1.8	0	N/A	1	0	0			2.00	0.30	HD Error	Reset HD connection	95	58
8/16	10	1425	1439	LM	Pick Up Signs	0	4.1	N/A	0	0	0			0.26	0.00			99	81
Total						3.1	82.5		21	0	6			13.79	0.30				

Olli and Steward Safety Checks

8

1. Morning/Evening Operational Briefs
2. Pocket Safety Steward Cards
3. Steward Safety Signs Posted inside Vehicle
4. No Seatbelts – NO Movement
5. Frequently Stop – Stay 100ft Back
6. Out of Service Signs

Frontside

Steward Safety Brief

Safety Is Your #1 Priority

1. Check Daily Operations
2. Check proper clothing
3. Check safety equipment
4. Check safety signs posted
5. Check Phone is charged
6. **No use of devices while moving**
7. **Seatbelts on or Olli doesn't move**
8. **Hand near the hand-break "at the ready position" to take over at anytime**
9. **Always *Remember***

You are the Safety Steward

If you don't feel safe at any time notify your PM immediately

Backside

EMERGENCY PROCEDURES

1. **Emergencies always dial 911 Car accidents/pedestrian injuries**
2. **Installation Police: 703-588-2809**
3. Render aid if you feel comfortable
4. Call Marci (PM): 703-340-6967
   - Matt (EVP): 480-319-1803
   - Eric (TECH): 480-790-4571
   - Todd (Install): 703-217-9307
5. **Any Olli Software issues contact**
   Mike Carpenter (RR):301-512-6671
   Eric (LM): 480-790-4571
6. **Any Olli Hardware issues contact**
   Eric (LM): 480-790-4571
   Taylor (LM):480-376-3103
7. **Always follow up with Emails to**
   mpatterson@local-motor.com
   mrivett@local-motor.com
   mcarpenter@roboticresearch.com
   ecekirdek@local-motors.com
   tjones@local-motors.com
   putney@roboticresearch.com

OLLI SAYS
PLEASE
FASTEN YOUR SEAT BELTS
YOUR SAFETY STEWARD
IS
GIOVANNI MEDINA

OLLI SAYS
PLEASE
FOR YOUR SAFETY
DO NOT DISTRACT
THE SAFETY STEWARD
For more Info on "Olli" go to
https://localmotors.com/meet-olli/

local motors

ISSUES/CONCERNS

9

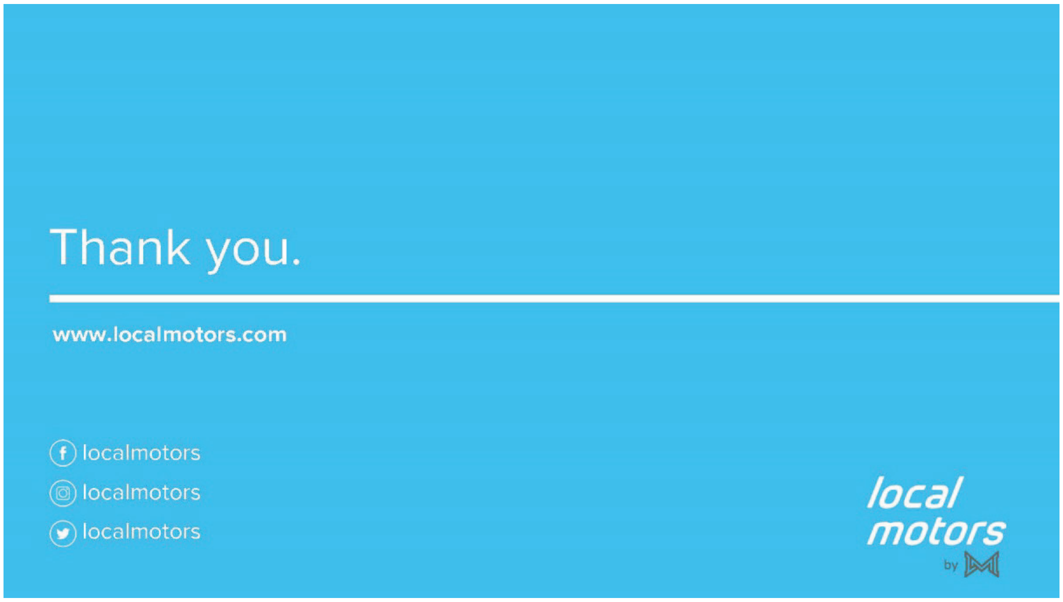
1. Only one charging station (2- Ollis): Challenging if we have additional Demos added to the schedule
2. Having to place/pick up signs (Maybe permanently leave signs out?)
3. No community communication strategy - Olli's not running a second shift? (Create additional sign on board annotating- "Only Bus 1 Running Today")
4. Drivers passing Olli during the stops in the crosswalk? (Coordinate with Police to be stationed in Spates or Bowling parking lot)

local motors

Next Step

10

1. **Working Deliverable Status Chart**
2. **Preparing word document for weekly report**
3. **Creating morning and evening bus schedule**
   16-19 Sep 0800-1000
   21-27 Sep 1430-1600



A comprehensive list of weekly reports from Local Motors is provided as a supplemental document.

Appendix H: Outline of Local Motors Report

Local Motors provided a final report that included many attachments. The structure of the report and documents are shown below, while the report itself is provided as a supplementary document.

LM Report Outline:

3. Final Report
4. Deliverables Chart
5. Deployment Package
6. Site Survey
7. Launch Checklist
8. RTK Check In/Out
9. Tool Kit Packing List
10. Onsite Vehicle Operational Checklist
11. Data Upload Document
12. RTK Setup Document
13. Site Setup Checklist
14. Olli Data Spreadsheet
15. MDOT Process
16. Safety Steward Job Description
17. Olli Vehicle Safety Briefing and Emergency Document
18. Safety Steward Pocket Brief
19. Shutdown and Closure Report
20. Robotic Research Olli Map.

Appendix I: Example Raw Data

Raw data format storage for Robotics Research data sets

```
// From PCAN-Gateways_Developer-Documentation_eng.pdf
// (Blockedhttps://www.peak-system.com/produktcd/Pdf/English/PCAN-Gateways_Developer-
Documentation_eng.pdfBlocked)
// 1.3.2 Structure of the Transmitted CAN data in the IP Frame
// Length        Field name          Meaning
//==========================================================================
// 2 Byte        Length              Fix value 0x24.  This corresponds to decimal 36 and
//                                   indicates the total length of the data packet including
//                                   this Length field in bytes.
// 2 Byte        Message Type        Fix value 0x80.  This value represents a CAN data frame.
// 8 Byte        Tag                 Not used in the current version.
// 4 Byte        Timestamp Low       Timestamp of CAN messages in microseconds.  The value
//                                   has no effect on the transmission of frames.  This
//                                   information is purely informative.
// 4 Byte        Timestamp High      Timestamp of CAN messages in microseconds.  The value
//                                   has no effect on the transmission of frames.  This
//                                   information is purely informative.
// 1 Byte        Channel             Not used in the current version.
// 1 Byte        DLC                 The Data Length Count (DLC) gives the length of the
//                                   CAN data in bytes.
// 2 Byte        Flags               Not used in the current version.
// 4 Byte        CAN ID              Bit 0-28 ID
//                                   Bit 29   Fix value 0
//                                   Bit 30   RTR
//                                   Bit 31   1 for Extended Frame, 0 for Standard Frame.
// 8 Byte        CAN Data            This field always contains 8x8 data bytes.
//                              Note: Use only as many bytes as the DLC indicates.  All
//                              the following bytes are available but invalid.
// The values are stored in Network Byte Order.  The CAN data is stored as single bytes // in ascending
order.
```

Appendix J: Example Dataset

The API has a number of calls that, when provided parameters (vehicle id, time, etc.), will return information for the following sensors and or faults.

The description of the API endpoints and available data can be found here

https://apidocs.ollionline.us/customer/

Below is an example of data returned from the endpoint

`/v1/diagnostics/aux?{cid}{vid}{date}{offset}`

Vehicle ID -
DateTime of data entry
Epoch Time of Sensor Reading from the following:
Brake Switch
Brake Light Left
Brake Light Right
Brake Light Middle
Light Low Beam
Light Hi Beam
Light Turn Right
Light Turn Left
Reverse Light
Running Light
Ignition Input
Door Enable
AC Request
AC Compressor Enable
ACTrinaryCompressorSw
ACTrinaryFanSw
HeatSwRequest
BlowerHiFront
BlowerHiRear
Horn Enable
Door Buzzer Enable
ACCompressorHV
vcu_KeySw
HVILBool
Heater Command Per
HVILDCPer
CoolingFanReqPer
AC Compressor Speed
AC Compressor HV Input
powertrainVehicleTripData
powertrainOnTime

bmsHVBatteryVoltage
bmsHVBatteryCurrent
BatteryCellTempMax
BMSState
VCUtoBMSStateReq (Vehicle Charging Unit)
BatteryFaulted
VCUStateDemanded
BrusaStateActive
VoltageSetpointRequest
ChargerTemperature
Phase1ACVoltage
Phase3ACVoltage
ChargerEnabled
InverterTemperature
InverterVoltage
InverterEnabled
InverterFaulted
MotorSpeed
TorqueRequest
FeedbackTorque
MotorTemperature
ParavanEnable
Joystick
IgnitionActive
VehMoving
ParavanCriticalFault
SteeringActive
ManualAPP
ParavanBackUpVoltage
ParavanBraking
ParavanSteering
brakeslightstires - Data for brake activation, signal lights, head lights, and tire pressure (TBD)
tailLights
brakeLights
signalLights
brakeActivated
emergencyButton
headLightsLowBeam
headLightsHighBeam
destination - Data for destination, stops
destReached
busStopNames
totalBusStops
nextDestination
prevDestination
maintenanceStopNames
totalMaintenanceStops

faults - Array of current faults
faultList
nav - Navigation data
yaw
roll
pitch
speed
valid
heading
latitude
longitude
status - Different states of Olli
olliState
doorStatus
batteryStatus
olliTransmission
doorstatus

Appendix K: ERDC Survey Questions

Fourteen question survey approved by the Human Research Protection Program of ERDC:

Survey Questions

Questions in this survey are intended to be answered by ***both riders and non-riders*** *of Olli. Please answer all questions to the best of your ability stemming from your observation of the autonomous vehicle.* This is an anonymous survey, do not record your name or any other identifying information on this form.

Activity: Human Factors JBMHH Survey for Autonomous Vehicles (AV)
Project Identification Number: 2019-02-NR
Investigator: Lance L. Larkin, PhD, CEERD-CERL

1. What is your age? (Only adults of 18 years and older.) ____________

2. Circle what describes you best:

Live or work on base	Work for the Dept. of Defense off-base	Do ***NOT*** work for the Dept. of Defense

3. Circle the most appropriate description of your interaction with the vehicle:

Safety Operator	Passenger	Observer (not riding on vehicle)	Other

4. How many times have you been a passenger on this vehicle?

Zero	1-2	3-4	5-9	10 or more

5. Is this your first time filling out this questionnaire (circle one)?

Yes	No

6. Have you been informed about the safe operation of this vehicle from any of the following sources? Circle all applicable answers. If you did not ride the vehicle, answer using any information you might have already seen about the vehicle.

Info via video display	Audio information	Steward/safety operator	Ads or publications	None

Directions: Please rate your agreement with each item based on your past or current experiences with the vehicle.

7. The vehicle is intelligent (circle one)

Strongly	Disagree	Somewhat	Neither	Somewhat	Agree	Strongly

8. The vehicle will be used regularly by people at Joint Base Myer-Henderson Hall (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

9. The vehicle is safe (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

10. The vehicle is trustworthy (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

11. If you were a rider: the vehicle and the ride were comfortable. (circle one)
    If you were ***NOT*** a rider: the vehicle appeared to give a comfortable ride.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

Directions: Please rate the acceptability of each item based on your past or current experiences with the vehicle.

12. The vehicle avoids other vehicles, obstacles, and pedestrians without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

13. The vehicle responds to traffic rules (e.g., road signs, road rules) without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

14. Please leave any open-ended feedback prompted by the survey. Write the number of the question if you are referring to your answers above.

Appendix L: Combined JBM-HH Survey

The combined 21-questions taken from Local Motors' user experience survey and CERL's rider and non-rider analysis survey:

Survey Questions

Questions in this survey are intended to be answered by ***both riders and non-riders*** *of Olli. Please answer all questions to the best of your ability stemming from your observation of the autonomous vehicle.* This is an anonymous survey, do not record your name or any other identifying information on this form.

Activity: Human Factors JBMHH Survey for Autonomous Vehicles (AV)
Project Identification Number: 2019-02-NR
Investigator: Lance L. Larkin, PhD, CEERD-CERL

1. On a scale from 0-10, how likely are you to recommend Olli to a friend or colleague (circle answer)?

0	1	2	3	4	5	6	7	8	9	10
Not at all likely										Extremely likely

2. What is your age? (Only adults of 18 years and older.) ___________

3. Why did you ride Olli today?

Curiosity Convenience Accessibility Analysis

4. How do you normally get around the base?

Walking Biking Base transportation Personal vehicle

5. Is the vehicle and the ride comfortable?

Not at all comfortable Uncomfortable Somewhat uncomfortable Acceptable Somewhat comfortable Comfortable Extremely comfortable

6. How would you rate the value of Olli operating on the base?

Extremely valuable Very valuable Moderately valuable Slightly valuable Not at all valuable

7. Were you provided enough information by people or other means to feel safe riding the vehicle? Select all applicable answers. If you did not ride the vehicle, answer using any information you might have already seen about the vehicle.

Word of mouth Steward/Safety Operator Media None Information operator publications

8. Which is the most appropriate description of where you work and/or live?

Live or work on base Work for the Dept. of Defense off-base Do NOT work for the Dept. of Defense

9. What features would make Olli better?

10. Select the most appropriate description of your interaction with the vehicle:

Safety Operator Passenger Observer (not riding on vehicle) Other

11. How many times have you been a passenger on this vehicle?

Zero 1-2 3-4 5-9 10 or more

12. Is this your first time filling out this questionnaire?

Yes No

Directions: Please rate your agreement with each item based on your past or current experiences with the vehicle.

13. The vehicle is intelligent. (Select one)

Strongly Agree | Agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Disagree | Strongly disagree

14. The vehicle will be used regularly by people at Joint Base Myer-Henderson Hall. (Select one)

Strongly Agree | Agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Disagree | Strongly disagree

15. The vehicle is safe. (Select one)

Strongly Agree | Agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Disagree | Strongly disagree

16. The vehicle is trustworthy. (Select one)

Strongly Agree | Agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Disagree | Strongly disagree

17. If you were NOT a rider: the vehicle appeared to give a comfortable ride.

Strongly Agree | Agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Disagree | Strongly disagree

Directions: Please rate the acceptability of each item based on your past or current experiences with the vehicle.

18. The vehicle avoided other vehicles, obstacles, and pedestrians without human intervention.

Perfectly Acceptable | Acceptable | Slightly acceptable | Neutral | Slightly unacceptable | Unacceptable | Totally unacceptable

19. The vehicle responded to traffic rules (e.g., road signs, road rules) without human intervention.

Perfectly Acceptable | Acceptable | Slightly acceptable | Neutral | Slightly unacceptable | Unacceptable | Totally unacceptable

20. Will you ride Olli again?

Yes No

21. Please leave any open-ended feedback prompted by the survey. Write the number of the question if you are referring to your answers above.

Appendix M: ERDC Online Survey

The information sheet given out to people when they did not have time to fill out a JBM-HH survey on site:

Survey Information Sheet

Welcome to the future of transportation! This survey allows you, as either a passenger or non-rider of the Olli Autonomous Vehicle (AV) shuttle, to offer your observations of AV operations. This short 10 question survey provides detailed information to the Army Corps of Engineers about your experience on Olli.

Please access the survey online through the link at https://www.surveymonkey.com/r/SYSVZSZ or use the following QR code.

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Activity: Human Factors JBMHH Survey for Autonomous Vehicles (AV)
Project Identification Number: 2019-02-NR
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14. ABSTRACT

Military installations serve as strategic staging areas that are integral to national security. The Army is currently reconsidering how it views its installations as part of the battle space under multi-domain operations, which includes technology modernization efforts, such as the rapidly expanding field of connected and autonomous vehicle (CAV) technology. The DoD community and military installations have an interest in investigating autonomous transportation systems to determine their potential role in a broad range of military applications. CAVs capture, store, and analyze tremendous amounts of data. Military installations need to understand the data systems and processes involved in CAV deployments. To that end, the Army is conducting pilot projects that deploy updated and commercially-available CAVs on installations and within adjacent communities to further demonstrate their use and conduct research and development to optimize and inform the integration of this emerging technology. This report documents the deployment of Autonomous Vehicle (AV) technologies at Joint Base Myer-Henderson Hall for a 90-day pilot study to evaluate a commercially-available AV.

15. SUBJECT TERMS
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